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CONTENTS

FEEDING EXPERIMENTS AT KARNAL, 1925-26 and 1926-27

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OBJECT OF EXPERIMENT.

To study the winter rationing of calves in the Punjab. The scheme of work was prepared by the Nutrition Section. The Feeding tests were carried out by the Superintendent, Imperial Cattle Breeding Farm, Karnal, and the data were dealt with by the Nutrition Section.

PROCEDURE.

During the first season the enquiry was confined to a comparison of coarse fodders. Wheat straw, *Sorghum* hay, Rice straw and *Dhub* hay were tested. Each of these roughages was fed as the sole coarse fodder to a group of five calves. The fodder was provided *ad lib* and the daily consumption by each animal was determined. All the animals received the same amount of concentrate, two lb. each daily. The animals were weighed daily. A full record of food consumption and live weight increase was obtained for a period of 14 weeks. At the end of the test, digestion experiments were carried out with a number of selected animals.

During the second season both roughage and concentrate rationing were studied. The work was confined to three roughages, namely, wheat straw, *sorghum* hay and rice straw. Sixteen calves were fed on each of these roughages. As usual, the fodder was provided *ad lib* and the daily consumption by each animal was determined. The concentrate rationing test was carried out as follows. Each group of sixteen calves was divided into two sub-groups of eight. One group received a high allowance, the other group a low allowance of concentrate. There were thus 3 roughages and each was tested with a high and low concentrate allowance. The concentrates during this season were fed in proportion to the live weights of the animals. The

groups receiving a low allowance were fed 1 lb. concentrate per 100 lb. live weight. The high concentrate allowance was given at the rate of 1·5 lb. per 100 lb. live weight. The concentrate allowance was adjusted periodically for each animal as it increased in live weight. Full records of food consumption and live weight increase for a period of 12 weeks were obtained. At the end of the test, digestion experiments were carried out with a number of selected animals.

Experimental Results, 1925-26.

Table I shows the group average fodder consumption.

Table I.

Weekly fodder consumption, 1925-26.

Wheat straw	In lb. per head per week		*Dhub* hay
	Sorghum hay	Rice straw	
38·95	45·95	40·85	35·57
36·87	40·03	46·12	36·88
46·07	35·05	41·20	35·00
44·58	37·30	42·45	36·85
38·90	40·05	46·11	35·05
36·80	42·95	54·00	41·15
39·20	41·05	49·00	42·10
47·90	40·05	52·95	38·95
48·60	37·45	55·17	43·80
48·35	42·85	52·15	41·75
37·17	42·19	53·42	42·93
37·20	42·55	57·00	47·40
36·00	41·00	55·65	46·05
31·90	42·00	52·15	43·95
Average 40·61	40·75	49·87	40·53

Every figure in this table is the average of 7 consecutive days' determinations with 5 animals. The figures show that marked changes in consumption occur from week to week with all the fodders. There is no evidence that these variations are due to climatic influences, because the incidence of the maxima for the different

fodders do not coincide. The striking fact brought out by the figures is that the rice straw group ate much more than any of the others.

TABLE II.

The weekly group average live weights.

TABLE II (*a*) LIVE WEIGHT				TABLE II (*b*)			
WEEKLY AVERAGES IN LB. PER HEAD 1925-26				WEEKLY CHANGES IN LIVE WEIGHT 1925-26.			
Wheat straw	*Sorghum* hay	Rice straw	*Dhub* hay	Wheat straw	*Sorghum* hay	Rice straw	*Dhub* hay
Group	Group	Group	Group	Group	Group	Group	Group
269	269	273	282	..	..	..	..
281	278	281	291	12	9	8	9
283	274	282	288	2	—4	1	—3
286	282	291	293	3	8	9	5
284	283	292	289	—2	1	1	—4
287	285	295	290	3	2	3	1
288	289	297	291	1	4	2	1
292	293	299	292	4	4	2	1
300	297	311	296	8	4	12	4
303	299	313	297	3	2	2	1
305	305	314	299	2	6	1	2
309	312	321	305	4	7	7	6
314	319	327	313	5	7	6	8
315	320	331	310	1	1	4	—3

Every figure in this table is the average of 7 weighings of 5 animals and represents 35 determinations. There are some sharp fluctuations in these figures also. Table II (*b*) shows these fluctuations more strikingly. By comparing Tables I and II it will be noticed that all sharp changes in live weight are assoicated with corresponding changes in food consumption. The experiment showed that of the fodders tested rice straw was most greedily consumed and produced the highest live weight increase. The result is of considerable economic significance, for the local belief is that wheat straw is superior to rice straw and it has consequently a higher market value. On the strength of these results the Karnal Farm has already effected considerable economies in rationing by using rice straw instead of wheat straw. The results obtained with *Dhub* hay are surprisingly poor. It was confidently expected that hay would give better results than straw. Unfortunately, further tests could not be undertaken at the time and we are not prepared to make a definite statement on the results of this single test.

The fluctuations in live weight and food consumption already referred to are illustrated in the accompanying Chart 1 in which data of Tables I and II are plotted graphically. The violent changes in roughage consumption which this Chart shows must be considered an unsatisfactory feature of the test. It is not

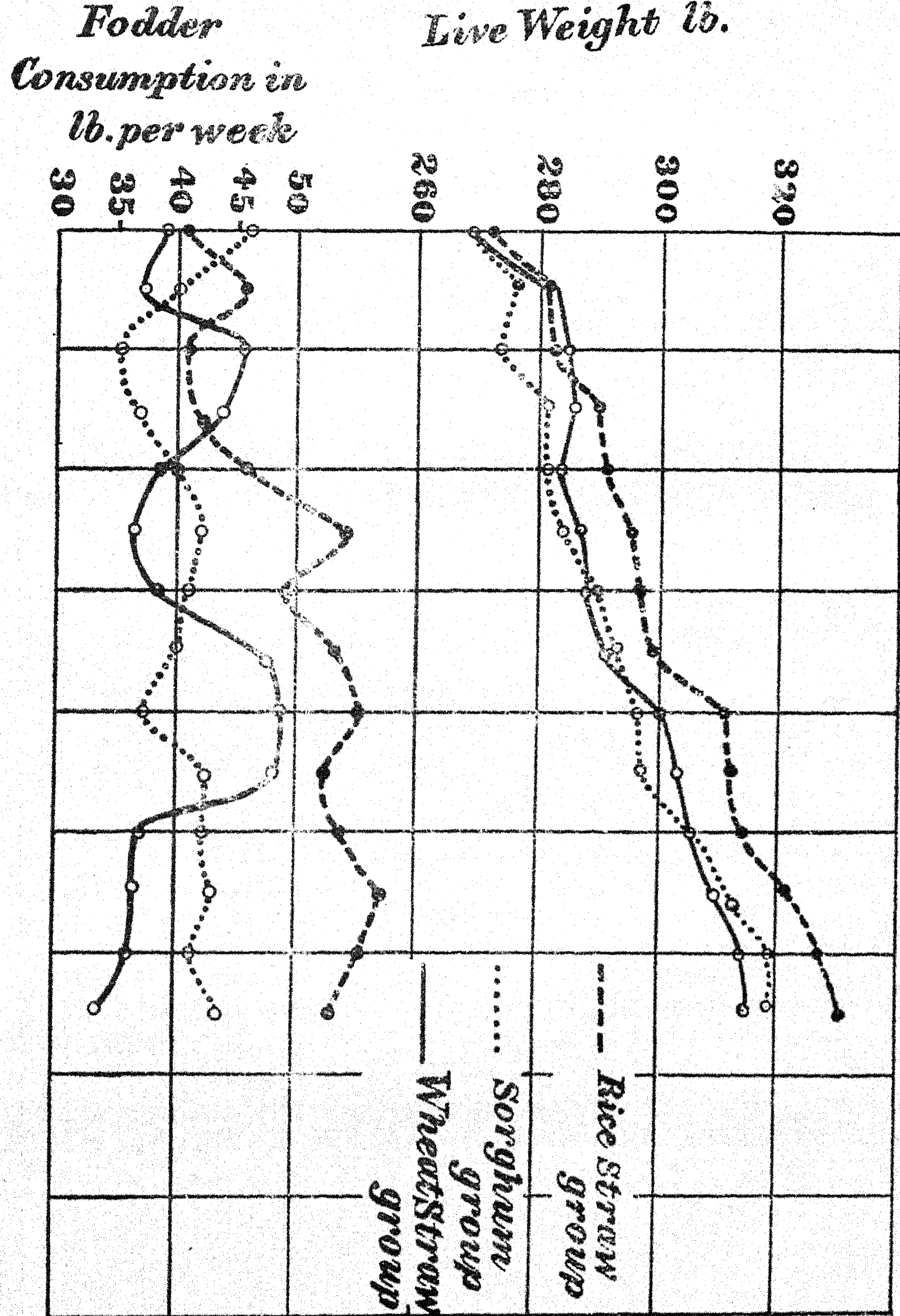
Fodder Consumption in lb. per week
Live Weight lb.
30
35
40
45
50
260
280
300
320
Rice straw group
Sorghum group
Wheat Straw group

CHART I (1926).

right that animals should go up and down to such an extent in consumption of fodder. The Nutrition Section has met with other cases of a similar nature which have been a discouragement. To realise the importance of this point, one has only to consider how much more profitable the feeding would have been if the highest consumption could have been maintained. Further experiments shed some light on this question. The point will be dealt with later. Here it is sufficient to notice the extent of fluctuation which may occur under such conditions of rationing. The following Table summarises the results obtained in 1925-26.

TABLE III.

Summary of the tests of 1925-26.

Group	Average consumption in lb. per head per week			
	Roughage	Concentrate	Total	Live weight increase in 91 days
Wheat straw	40·61	14·00	54·61	46
Sorghum hay	40·75	14·00	54·75	51
Rice straw	49·87	14·00	63·87	58

EXPERIMENT RESULTS, 1926-27.

Table IV shows the food consumption and live weights on the high concentrate rations.

TABLE IV.

High concentrate rationing 1926-27.

Roughage consumption*			Concentrate consumption*			Live weights		
Wheat straw	*Sorghum* hay	Rice straw	Wheat straw	*Sorghum* hay	Rice straw	Wheat straw	*Sorghum* hay	Rice straw
Group	Group	Group	Group	Group	Group	Group	Group	Group
26·60	31·33	33·16	22·97	22·88	24·72	233	235	243
26·01	35·14	34·56	24·38	24·56	25·75	246	248	256
26·61	34·69	37·11	26·01	26·25	26·38	256	259	264
27·35	33·22	35·41	26·59	26·92	27·44	257	264	269
27·12	34·60	32·56	27·09	27·44	27·92	259	268	275
28·36	34·21	31·64	27·08	27·73	28·54	266	278	284
26·75	30·44	32·49	27·60	28·89	29·52	272	282	291
27·61	31·90	32·61	28·39	29·54	30·19	278	288	299
30·32	32·87	35·01	29·04	30·02	31·17	289	298	308
31·03	35·65	37·64	29·69	30·83	31·99	294	305	319

* lb. per head per week.

High concentrate rationing 1926-27—contd.

Roughage consumption*			Concentrate consumption*			Live weights		
Wheat straw	*Sorghum* hay	Rice straw	Wheat straw	*Sorghum* hay	Rice straw	Wheat straw	*Sorghum* hay	Rice straw
Group	Group	Group	Group	Group	Group	Group	Group	Group
29·29	33·62	34·64	30·52	31·83	32·81	302	313	328
29·67	34·49	34·44	31·34	32·49	34·12	308	317	333
31·72	33·45	35·61	32·15	32·31	34·78	318	326	345
29·92	36·63	33·88	32·86	33·05	35·61	..	..	..
28·15	34·74	36·81	33·46	33·93	36·10	..	..	..
Average 28·43	33·80	34·50	28·61	29·24	30·47	276	281	294

* lb. per head per week.

In this table each figure is the average of 7 consecutive days' weighments with 8 animals and represents 56 separate determinations. It will be noticed that *sorghum* was eaten quite as well as rice straw in this test. The low concentrate rationing figures to be considered later confirm this result. The fact is that the *sorghum* used during the first season was somewhat below average quality. The results obtained in the second season are probably more typical for average quality *sorghum*. It is interesting to observe that the fluctuations in consumption of fodder are not serious in this test. The following table summarises the results obtained with high concentrate rationing.

TABLE V.

Summary of high concentrate test.

Group	Average roughage consumption	Average concentrate consumption	Total consumption	Live weight increase in 84 days
Wheat straw	28·43	28·61	57·04	85
Sorghum hay	33·80	29·24	63·04	91
Rice straw	34·50	30·47	64·97	102

Highest consumption and greatest increase were obtained with rice straw. Sorghum consumption is not far behind. Wheat straw is definitely below the others.

Table VI shows the food consumption and live weight increase on the low concentrate allowance. Each figure in this table represents 56 separate determinations. In this experiment the *sorghum* group has definitely surpassed the rice straw group though the difference is slight. To show the extent of the fluctuations week by week the figures of this table are given in graphic form in Chart II. The chart shows

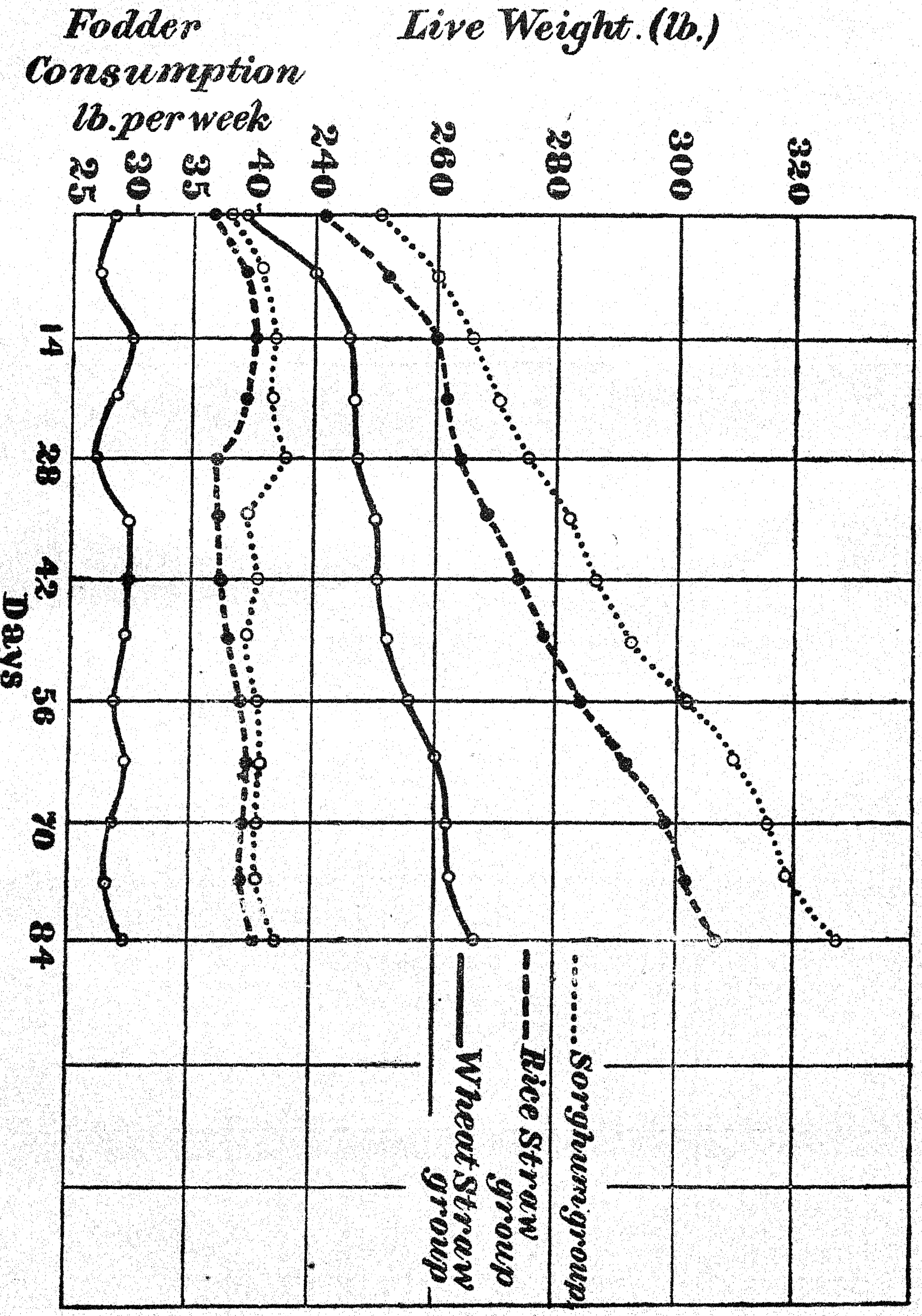

CHART II. (1927)

that fodder consumption was remarkably uniform. The contrast between Charts I and II in this respect should be noted. There is no doubt that serious fluctuations have been avoided in the second season's tests. The chart shows that *sorghum* and rice straw were well relished and produced rapid increase in live weight. The consumption of wheat straw was far below the other fodders. It also produced slower increase in live weight. The data for low concentrate feeding are summarised in Table VII.

TABLE VI.

Low concentrate rationing 1926-27.

Roughage consumption			Concentrate consumption			Live weights		
Wheat straw	*Sorghum* hay	Rice straw	Wheat straw	*Sorghum* hay	Rice straw	Wheat straw	*Sorghum* hay	Rice straw
Group	Group	Group	Group	Group	Group	Group	Group	Group
28·64	37·96	36·41	15·75	16·19	16·62	228	251	242
26·84	40·49	39·42	16·59	17·50	16·99	240	260	253
30·21	41·98	40·36	16·85	18·26	17·86	247	267	260
29·02	41·82	38·99	17·18	18·81	18·06	247	272	262
27·04	42·86	35·94	17·29	19·16	18·39	247	277	264
29·68	39·28	37·13	18·01	19·25	18·61	250	282	268
29·91	40·35	37·61	17·50	19·58	18·71	251	287	274
29·83	39·48	37·92	17·61	20·02	19·14	253	293	278
29·11	40·28	38·83	17·82	20·35	19·36	257	301	283
30·32	40·88	40·54	17·82	20·90	19·80	260	309	292
29·16	40·13	39·86	18·16	21·55	21·32	262	316	299
28·48	39·73	37·84	19·04	22·11	22·26	263	319	301
30·09	42·32	39·65	18·87	22·22	22·42	267	329	308
29·62	41·64	40·78	19·34	22·78	22·94	..	..	..
29·43	42·61	41·40	19·40	22·78	22·99	..	..	..
Average 29·16	40·79	38·85	17·81	20·10	19·70	248	290	275

TABLE VII.

Summary of results with low concentrate feeding.

Group	Average weekly consumption			
	Roughage	Concentrate	Total	Live weight increase in 84 days
Wheat straw	29·16	17·81	46·97	39
Sorghum hay	40·79	20·10	60·89	78
Rice straw	38·85	19·70	58·55	66

Rate of growth in relation to size.

On examining the live weight figures more closely, it is found that the increase is not simply related to the nature of the ration but depends also to some extent upon the size of the animal. To study this point, the animals have to be redistributed into new groups, each of which contains an equal number of representatives of the three different fodders. Taking first the experiments with the higher rate of concentrate feeding, the two animals having the lowest average live weight amongst the wheat straw eaters, the *sorghum* eaters and the rice straw eaters have been selected to form a new group of animals of minimum live weight. In this group all the fodders are equally represented and the only characteristic of the group is that it represents the smallest animals. From the remaining animals again the two lightest have been taken out of each group to form a new group. Proceeding in this way all the animals which were in the high concentrate feeding test have been arranged in four new groups of increasing live weight. Exactly the same procedure has been applied to the animals in the low concentrate feeding test. They have also been divided into four new groups of increasing live weight. It must be clearly understood that these new groups all contain an equal number of representatives of each fodder. The results are therefore altogether uninfluenced by any difference that there might be in the three fodders and show us simply the effect of size upon food consumption and growth. The data obtained in this way are shown in Table VIII.

Table VIII.

Food consumption and growth in relation to size.

A. High concentrate test.

Group	Average live weight	Live weight Increase	Actual food consumption per head			Food consumption per 100 lb. live weight		
			Concentrate	Roughage	Total	Concentrate	Roughage	Total
1	224	76	346	426	772	156·2	190·1	344·5
2	274	92	431	471	902	157·3	171·9	329·3
3	300	96	468	506	974	156·0	168·7	324·7
4	331	108	522	529	1,051	157·7	159·8	317·5
B. Low concentrate test.								
1	217	48	231	483	714	106·5	222·6	329·1
2	258	68	273	546	819	105·8	211·6	317·4
3	282	60	299	528	827	106·4	187·2	293·6
4	331	63	341	626	967	105·8	200·0	305·8

(Each figure in these tables is the average obtained from the daily food consumption of 6 animals for 12 weeks).

It should be observed that there is nothing remarkable in the regularity with which concentrate is consumed. Concentrate was fed accurately in proportion to live weight, one lot receiving 1·5 lb. the other lot 1·0 lb. per 100 lb. live weight. The figures for concentrate consumption merely show that the proposed rationing was accurately adhered to during the test of 84 days. There is however a remarkable regularity in the consumption of roughage by the animals in Table A. This regularity which may almost be called astonishing is undoubtedly due mainly to the high rate of concentrate feeding. About half the food consisted of easily digested concentrate accurately rationed out. There was little room left for violent fluctuations. Nevertheless the regularity in roughage consumption is striking and seems to have a real significance. Table A brings out the following facts:

1. Concentrate consumption is practically constant per 100 lb. live weight for all four groups. This was artificially brought about by feeding concentrate in proportion to live weight.
2. The roughage consumption per 100 lb. live weight shows a small but very regular decline with increasing live weight.
3. A consequence of this decline in roughage is that we have a regular decline in total food consumed per 100 lb. live weight with increasing live weight.
4. It seems to be a fact that on the rationing principle employed in these tests the rate of growth increases with increasing live weight.

The last point is easy to understand if we consider the case of animals weighing 100 lb. and 200 lb. respectively. If the ration for 100 lb. live weight provides a margin for growth, then an animal double the size receiving double the ration would have about double the margin for growth. In fact, the rationing procedure becomes more generous as the animal increases in live weight. These theoretical considerations are borne out in two ways by the results of Table A.

1. The larger animals definitely show a greater rate of growth.
2. The smaller animals eat relatively more roughage (though normally they should eat relatively less) than the larger animals, showing thereby that they need more food. The larger animals, which have a better capacity for roughage, on the other hand eat less because they have ample nourishment from the concentrate.

The results of Table B are much less regular, probably because the accurately rationed concentrate formed a smaller proportion of the total food thereby leaving more room for fluctuations. But the results of this table, in spite of irregularities, do confirm in a general manner the conclusions arrived at above. For example, the smallest group made least live weight increase and consumed proportionately most roughage. It is perhaps desirable to state here that concentrate rationing in

proportion to live weight is a device adopted by the Nutrition Section for experimental purposes only. It is not recommended in practice, but the results which it has yielded in these experiments are of direct practical use.

Food consumption and growth in relation to the nature of the rationing.

The figures relating to food consumption and growth are summarised for reference in Table IX.

TABLE IX.

Summary of food consumption data from three feeding tests.

—	Group	Average weekly consumption in lb. per head			Group average live weight	Actual live weight increase in 100 days
		Roughage	Concentrate	Total		
1925-26 Test .	Wheat straw . .	40·60	14·00	54·61	292	51
	Sorghum hay .	40·75	14·00	54·75	295	57
	Rice straw . .	49·87	14·00	63·87	301	64
1926-27 Test .	Wheat straw . .	29·16	17·81	46·97	247	46
	Sorghum hay .	40·79	20·10	60·89	290	92
	Rice straw . .	38·85	19·70	58·55	275	78
1926-27 High Concentrate Test	Wheat staw . .	28·43	28·61	57·04	276	101
	Sorghum hay .	33·80	29·24	63·04	281	108
	Rice straw . .	34·50	30·47	64·97	294	122

Owing to unavoidable initial differences in live weight and to differences produced by unequal rates of growth under the various rationing methods, there are considerable differences in the average live weights of the groups which have to be compared. As food consumption is proportional to live weight (other things being equal), the figures for consumption cannot be compared directly. They must be computed to refer to a uniform live weight and the average live weight of all the groups, namely 283 lb., has been selected as the basis. Calculated to this standard there is a minimum of alteration in the figures. It is perhaps necessary to emphasise here that this calculation to a common standard is a perfectly legitimate and reliable procedure, which is generally warranted and, in the present instance, is also com-

pletely justified by the data in Table VIII. The consumption converted to a common standard is given in Table X.

TABLE X.

Computed consumption for an animal of average live weight (283 lb.)

—	Group	Average weekly consumption in lb. per head		
		Roughage	Concentrate	Total
1925-26 1st Test	Wheat straw	39·27	13·57	52·84
	Sorghum hay	39·09	13·43	52·52
	Rice straw	46·89	13·16	60·05
1926-27 Low concentrate 2nd Test.	Wheat straw	33·41	20·41	53·82
	Sorghum hay	39·81	19·61	59·42
	Rice straw	39·98	20·27	60·25
High concentrate 3rd Test	Wheat straw	29·15	29·34	58·49
	Sorghum hay	34·04	29·45	63·49
	Rice straw	33·21	29·33	62·54

The figures in this Table are a true expression of the feeding results. They show a number of interesting facts. The first point to note is that there was a regular gradation of concentrate used in the three tests. The proportion was lowest in the 1st test. The second test provided more and the third test very much more. Secondly, it has to be noted that roughage consumption decreases as the concentrate is increased. This holds good for any one roughage. The 2nd test with *sorghum* does not quite fall in line with the other tests, because there is no drop between the 1st and 2nd tests. The fault, however, does not lie in the 2nd test, but in the 1st. It has already been mentioned that the *sorghum* used in the 1st season was of poor quality. It is seen now that the *sorghum* consumption was too low in this test. In fact, the table confirms what has already been said about the quality of the *sorghum*. Thirdly, it has to be noted that although the roughage comsumption decreases, the total food consumption increases steadily with increasing concentrate. Fourthly, comparing the different fodders it is seen that *sorghum* and rice straw give almost identical results in the 2nd and 3rd tests. It may be concluded that

these fodders are approximately equally well consumed. Wheat straw is clearly less liked. Naturally, with wheat straw as with the other fodders there is a steady increase of total food consumption as the concentrate is increased, but it is always well below the rice straw figures, although as might be expected the difference between the good and bad fodders becomes less marked as the proportion of concentrate is increased. From a practical feeder's point of view, the actual proportions of concentrate and roughage consumed under the three test conditions are of great interest.

Live weight increase. With regard to food consumption the results of these tests are perfectly clear and definite. It is more difficult to decide on the relative productive values of the rations. In the first place the actual live weight increases observed can only be considered approximate values, because the increases were small in most cases. Secondly, a more serious difficulty arises out of the fact noted earlier, namely, that the rate of increase is materially influenced by the live weight of the animal under test. There were considerable differences in the live weights of the groups tested and we have no very reliable means by which allowances can be made for these variations in live weight. The results of Table VIII are our only guide in this matter. Taking all the available facts and figures into consideration, the following statement seems permissible.

1. The first test gave the smallest increase with all 3 fodders. On this ration wheat straw and rice straw appear to yield about 50 and 60 lb. live weight increase respectively.
2. The second ration gives higher rates of increase. Wheat straw may yield 65 lb., rice straw and *sorghum* 80 to 85 lb.
3. The high concentrate ration produces an increase of over 100 lb. in all cases. Wheat straw probably gives slightly lower results than the other fodders. All these live weight increases refer to a period of 100 days and to animals of 283 lb. average live weight.

Digestion Experiments.

1. *Digestion of rice straw rations.*

Digestion experiments were carried out with a few animals during each season. The most complete tests were made with rice straw and these will be considered first. The ration of 1925-26 was tested with 2 animals. The two rations of 1926-27 were each tested with three animals. The results are shown in the accompanying table.

TABLE XI.

Digestibility of rice straw group rations.

	Ration consumed					Digestion coefficients					Live weight	Consumption per 100	Calf No.
	Roughage	Concentrate	Total	R/C.	Per cent. Protein	Dry Matter	Organic matter	Protein	Ether extract	Carbohydrates			
1925-26 test	2690	1157	3847	2·33	8·84	53·8	60·7	55·2	73·9	60·6	309	1245	1
	3077	1157	4234	2·66	8·22	52·6	58·7	53·9	72·3	58·6	318	1332	2
Average	2833	1157	4040	2·45	..	53·2	59·7	54·6	73·1	59·6			
1926-27 Low concentrate	2621	968	3589	2·71	7·89	53·6	59·1	57·1	72·0	58·9	266	1349	3
	2104	1016	3120	2·07	8·88	55·7	61·4	60·3	74·5	61·2	271	1151	4
	2770	1258	4028	2·20	8·64	55·6	61·5	60·5	72·8	61·2	342	1178	5
Average	2498	1081	3579	2·31	..	55·0	60·7	59·3	73·1	60·4			
1926-27 High concentrate	1796	1524	3320	1·18	11·23	56·2	61·6	65·9	75·4	60·4	279	1190	6
	2290	1814	4104	1·26	10·94	56·0	61·4	64·0	73·4	60·6	325	1263	7
	1711	1959	3670	·87	12·56	57·7	63·2	67·3	78·4	61·8	354	1037	8
Average	1932	1766	3698	1·09	..	56·6	62·1	65·7	76·1	60·9			

The data relating to food consumption have an important bearing on the digestion results and must be considered first. In each test concentrate was fed in definite amounts according to the schedule applicable to the test. All variations in total food consumption are therefore due to differences in roughage consumption. Calves 2 and 3 ate proportionately much more roughage during the test than was generally consumed by animals in these groups. Their rations during the digestion experiment contained relatively less concentrate and consequently also less protein and the R./C. ratios are abnormally high. The total food consumption per 100 lb. live weight is high for the same reason. Calf No. 8 ate less roughage during the digestion experiment than it should have done. In this case the proportion of concentrate is abnormally high, the per cent. of protein is high and the total food consumption is abnormally low. It will be seen that these circumstances have had an appreciable effect on the digestion results.

Digestion of protein. The concentrate fed in 1926 differed somewhat from the concentrate fed in 1927. Therefore the digestibility of protein during the 2 seasons is not strictly comparable. The figures show in fact that the digestibility was somewhat lower in 1926. It is more important to note that protein digestion varies with the percentage of protein in the food. Within each group the digestibility is higher when the percentage is higher. The relevant figures shown in the table make it clear that the higher digestibility is associated with a higher proportion of concentrate in the ration. The variations in protein digestion in all these tests are perfectly regular and are accounted for quite satisfactorily by the explanation given above. So far the digestion results must be considered highly satisfactory.

Digestion of dry matter and organic matter. There are variations in the digestion of organic matter and dry matter in each group. It will be noticed that these variations also run parallel with the proportion of concentrate in the ration, and are therefore satisfactorily accounted for. It must be admitted that we have been fortunate in these rice straw tests. The animals have behaved in a remarkably uniform manner as regards digestion although they were far from uniform in the consumption of roughage.

Digestion of carbohydrates. It is very interesting to notice that the average digestion of carbohydrates by the three groups is almost identical. It is true that the bulk of the ration (or the proportion of protein) has an appreciable effect, the digestion being distinctly less when the protein content of the ration is low, but the difference is not great and no serious error would result if the same coefficient were used for all the rations provided that the animal concerned was not eating abnormally. It will be noticed that the digestion of carbohydrate only departs appreciably from the normal when the animal is eating very abnormally, for example, when the consumption of roughage becomes exceptionally high (R/C 2·66 in 1st test, R/C 2·70 in 2nd test) or exceptionally low (R/C ·87 in the 3rd test). The variations in these three instances are in the expected direction. The remaining figures are almost identical. These results show clearly that carbohydrate digestion remains

constant under the three very different conditions of rationing tested. Only in extreme variations in roughage consumption is the digestion of carbohydrate appreciably affected. This is an important result.

2. *Digestion of Sorghum rations.*

Only two tests were made with this ration. The high concentrate group was not tested. The results are shown in the accompanying table.

TABLE XII.

Digestion of sorghum rations.

—	Ration consumed					Digestion coefficients					Live Weight
	Roughage	Concentrate	Total	R/C.	% Protein	Dry matter	Organic matter	Protein	Ether extract	Carbohydrates	
1925-26 tests	2288	1157	3445	1·98	8·80	58·4	61·9	60·0	74·0	61·7	337
	2662	1157	3819	2·25	8·22	53·0	57·0	54·2	75·5	56·6	336
Average	2475	1157	3632	2·14	..	55·7	59·4	57·1	74·7	59·1	
1926-27 Low concentrate . .	2357	1161	3518	2·03	9·15	57·6	60·7	60·9	76·4	60·0	310
	2513	1307	3820	1·92	9·37	58·5	61·4	61·4	71·0	60·8	350
	1778	1210	2988	1·47	10·47	59·0	62·6	65·2	75·7	61·9	319
Average	2216	1226	3442	1·81	..	58·4	61·6	62·5	74·4	60·9	

It is necessary to lay special stress on the relationship between the per cent. of protein in the food and its digestibility. The relationship observed in the case of rice straw holds good without exception in these *sorghum* results. In other respects too the points noted in the rice straw tests are seen in the *sorghum* figures. The food consumption, the per cent. of protein in the ration and the R/C ratios show the anticipated effects on digestion with the same regularity. One result in this table is not so satisfactory however. The digestion of protein and carbohydrate by Calf No. 2 is abnormally low. The variation is in the right direction. That is to say, with a low proportion of concentrate, low percentage of protein, high rate of food consumption and high R/C ratio, we do expect (judging from the rice straw results) a drop in digestibility of both protein and carbohydrates, but the drop is greater than anticipated. Owing to this one abnormal figure, the carbohydrate digestion of the *sorghum* rations is not quite certain. Taking all the results together, it must be concluded that the digestibilities of the rice straw and *sorghum* rations are so nearly identical in every respect that they cannot be distinguished from one another. This is a definite and important piece of information.

3. *Digestion of wheat straw rations.*

In contrast to the results with rice straw and Sorghum which are remarkably regular and convincing the data obtained with wheat straw are worthless. In 1926 the carbohydrate digestion was found to be 59·0 per cent. and 56·6 per cent. with the two calves tested. These figures might give us a rough estimate, but they cannot be relied on because the low result was obtained where the proportion of concentrate was high. The protein digestion figures 55·7 per cent. and 57·7 per cent. however vary in accordance with the percentage of protein in the two rations. The results obtained in 1927 with three calves are worse. The carbohydrate digestion figures were 55·1 per cent., 58·2 per cent. and 60·3 per cent. and these variations bear no relation to the R/C ratios. In this test even the protein digestion is irregular. The fact that these irregularities occurred two years in succession with wheat straw while, under identical conditions, *sorghum* and rice straw gave concordant results seems significant. It has to be borne in mind that the calves on the wheat straw rations were not making good live weight gains. They were not in a thrifty state and digestion may have been irregular on that account.

Observations on the digestion of crude protein nitrogen in the rice straw rations.

The six animals of the rice straw groups of 1927 consumed rations which consisted of the same materials, namely, rice straw with a low percentage of nitrogen and concentrate with a high percentage of nitrogen but the proportions of straw and concentrate differed with the different animals. The type of ration consumed by each animal is most accurately defined by the nitrogen percentage, because this figure is actually an expression for the proportion of roughage and concentrate in

the food. The digestion experiments have shown that there is a close relationship between the percentage of nitrogen in the food and in the fæces. The data are given in the accompanying table.

TABLE XIII.

Relation between nitrogen content of food and fæces.

Percentage nitrogen.	
In food.	In fæces.
1·263	1·167
1·422	1·276
1·383	1·190
1·799	1·402
1·750	1·433
2·010	1·555

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These figures are shown graphically in Chart III. It appears that the nitrogen percentage in the fæces is directly proportional to the nitrogen percentage in the ration, the relationship between the two being represented by the thick line on the chart. With this established relationship it is permissible to calculate the nitrogen percentage of the fæces from any ration falling within the range of the tests. Of the total nitrogen digested from any such ration the amount obtained from the concentrate can be calculated from known digestion coefficients. Such a calculation gives the following results for three rations falling within the range of the tests.

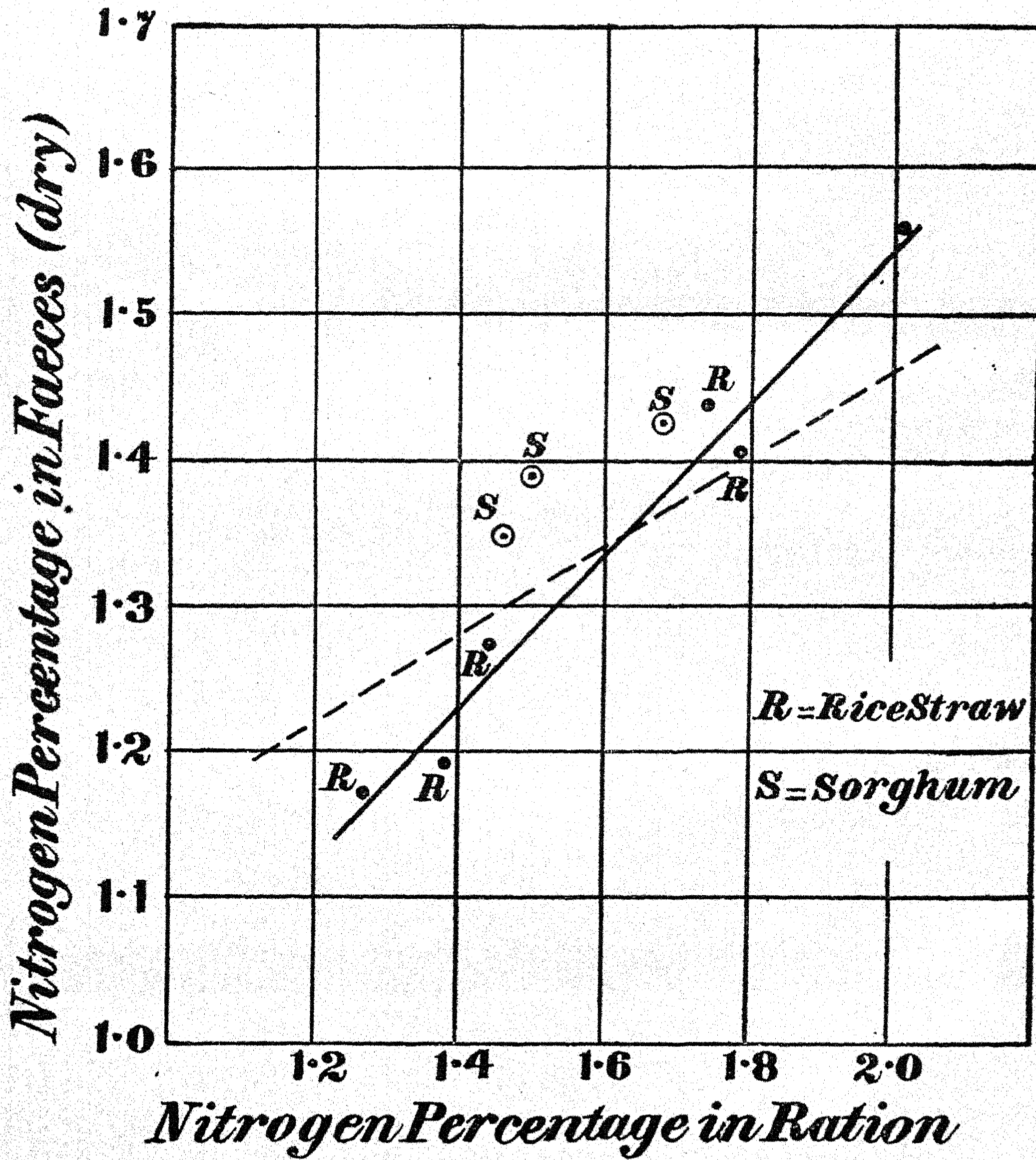

CHART III.

TABLE XIV.

Calculated nitrogen digested for rice straw rations.

—	Ration 1	Ration 2	Ration 3
Nitrogen in ration	45·88	59·13	72·38
Nitrogen in fæces	19·30	21·50	23·50
Nitrogen digested	26·58	37·63	48·88
Nitrogen digested from concentrate	25·77	38·08	50·39
Difference	+·81	—·45	—1·51

The regular increase seems significant, but the differences are small and might be due to experimental error. If an experimental error is involved, the variations can be allowed for and a series of corrected averages obtained. Such corrected averages would fall along the dotted graph in Chart III. Our evidence is not very strong, but it seems unlikely that the experimental points can be interpreted to represent the dotted line. There is some indication therefore that the regular increase noted in the table above must be accepted at least in a qualitative sense. This means that the digestibility of the concentrate has been overestimated. It appears from the data that the calves digest about 4 per cent. less protein than was expected from the known digestion coefficients. This is good efficiency for a calf. The figures show further, that the nitrogen of the rice straw has an appreciable effect upon the amount of protein digested and upon the nutritive ratio of the ration. The importance of this subject which is being more fully studied at Bangalore will become clearer in the following pages.

For *sorghum* rations three results comparable with the rice straw figures are available. They are shown on the Chart as circles and indicate that rice straw and *sorghum* are about equal in this property. It may be noted that all the *sorghum* figures are slightly less favourable than the rice straw figures.

RELATIONSHIP BETWEEN FOOD DIGESTED AND GROWTH.

The average amounts of nutrients digested daily during the feeding tests have been calculated from the data in tables X, XI and XII. The results are shown in the accompanying table.

TABLE XV.

Amounts of nutrients digested (grams per day).

—	Protein	Ether extract	Carbohydrates	Total organic matter	Total digestible nutrients	Nutritive ratio	Live weight increase in 100 days	Starch equivalents
1925-26.								
1. Wheat straw group .	117	59	1510	1686	1765	14·12	50	3·37
2. Sorghum group .	129	64	1493	1686	1671	12·71	50	3·37
3. Rice straw group .	139	65	1551	1755	1853	12·33	60	3·73
1926-27 Low concentrate								
4. Wheat straw group .	184	49	1484	1717	1782	8·70	65	3·76
5. Sorghum group .	201	54	1678	1933	2005	8·96	85	4·06
6. Rice straw group .	207	54	1531	1792	1864	8·02	80	4·06
1926-27 High concentrate								
7. Rice straw group .	281	67	1588	1936	2025	6·21	115	4·67

The figures for digested nutrients may be accepted as reliable. The live weight figures, especially those in which the increase is small, cannot be expected to give an accurate estimate of the increase in body substance. The column designated Total digestible nutrients is the sum of carbohydrates, proteins and 2·3 times the ether extract. It represents food values or food units in a form which is extensively used. Without laying too much stress on the live weight figures, it is apparent that neither the total organic matter digested nor the total digestible nutrients are an accurate measure of the values of the rations. For example, they make ration 3 equal to 6 and ration 4 equal to 7, whilst there can be no doubt from the live weight figures that these 2 pairs of rations differed very materially. It may be noticed here that the only figure derived from the digestion experiments which gives a reasonably fair measure of the value of the rations is the figure for digested protein. The parallelism between protein digested and live weight increase is fairly close. Such a result is not to be expected generally. It has been obtained in these tests on account of special circumstances which will become clear later. The most reliable method we possess at present for estimating values of rations is based on net energy values of starch equivalents. It is evident that the estimated starch equivalent values of the rations run very nearly parallel to the live weight figures and the results in the two columns tend to corroborate one another. But 3·37 starch equivalents are a bare maintenance for animals of this size and leave practically no margin for growth. It is probable that the live weight increases in groups 1 and 2 do not represent an equivalent increase in body substance. It should be mentioned here that if the ordinarily accepted starch equivalent values for fodders had been

employed in these calculations, the rations for the 1st and 2nd groups would have appeared inadequate for maintenance even. On the strength of work done at Bangalore, higher values have been given to these Indian fodders and the results obtained in the Karnal experiments under discussion offer some support for such higher values.

Relationship between protein requirement and fodder consumption.

All other points in Table XV are dwarfed by the remarkable protein figures. The amount of protein digested is far below European standards. It may be mentioned here that the concentrate fed in 1925-26 was considered a normal economic allowance for the prevailing conditions. The low concentrate allowance of 1926-27 was distinctly higher, whilst the high allowance was not considered a practical proposition and was fed only to amplify the experiment. Table XV shows that this high ration provided 280 grams of digestible protein, the other rations of the same year provided 200 grm. and the rations of 1926-27 provided 117 to 137 grams. As a contrast to these figures, English and American standards recommend 350 to 400 grams and the maintenance allowance alone is stated to be 137 grams. The nutritive ratio—the proportion of other food stuffs to protein—emphasises the same shortage of protein in our rations. English and American standards recommend a nutritive ratio of 5·1 to 5·6. Our best ration, with high concentrate, had a nutritive ratio of 6·2. The 1925-26 rations had a nutritive ratio of about 13. In Europe or America such a ration would be considered just bearable by a mature bullock at rest. Our animals are hardy, but they cannot be expected to make any headway with such rations. The rationing of 1925-26 was wrong and there is a very interesting piece of indirect evidence to show that it was wrong.

Turning to the food consumption charts, it will be recollected that fodder consumption fluctuated violently from week to week in the tests of 1925-26. It seems more than likely now that the fluctuations observed in the Karnal experiments are due to the very wide nutritive ratio of the rations. The animals are hungry, they want to eat more and they do so for a time, but the composition of the food becomes progressively more abnormal as the consumption of fodder increases, and they go off their feed. As the proportion of fodder decreases, the nutritive ratio is improved and in due course appetite returns. The fluctuations are no doubt favoured and synchronised by small changes in the nitrogen content of the fodder which would have a very appreciable effect on the nutritive ratio. With a different ration having a narrower nutritive ratio, such fluctuations should not occur. It will be recollected that serious fluctuations did not occur in 1926-27 and we may conclude that the nutritive ratio of these rations was just good enough to avoid this very unfavourable symptom. These observations provide a means for deciding on suitable economical and efficient concentrate rations. It appears that with our hardy animals, when rapid growth is not required, it is not necessary

to use such narrow nutritive ratios as are employed in Europe. The ration should, however, provide sufficient protein to ensure regular consumption of fodder.

Summary.

1. Tests carried out during two consecutive seasons showed that rice straw is eaten more readily and produces better growth than wheat straw. Locally, this is a result of economic significance. Good *sorghum* and rice straw are approximately equally well consumed and appear to have similar nutritive effects.

2. Experiments on the rationing of concentrate have yielded very definite results of practical value. The actual quantities of fodder consumed and the growth obtained with different rates of concentrate feeding are of particular interest. Figures have also been obtained to show the relative amounts of concentrate required by animals of different live weight to maintain them on the same plane.

3. Digestion experiments showed that appreciable changes in the digestion of protein and carbohydrate occur when the amount of protein in the ration is varied. The digestibility increases with the amount of protein. It is noteworthy also that the rice straw and *sorghum* rations gave almost identical digestion results.

4. The digestion figures relating to protein are remarkable. It has been shown that our test rations provided much less digestible protein than European standards recommend. The nutritive ratio was likewise excessively wide in certain cases.

5. The relationship which was found to exist between the percentage of nitrogen in the food and the fæces may be of value in differentiating fodders.

6. Very serious fluctuations of fodder consumption were observed in some tests. Such fluctuations are a bad symptom and show that the ration was unsuitable. It is a significant fact that the most serious fluctuations occurred with those rations in which the protein was low.

7. It appears that, when rapid growth is not required, our hardy animals can thrive on rations with much wider nutritive ratios than those recommended in European standards. The ration should, however, provide sufficient protein to ensure regular consumption of fodder. When serious fluctuations commence, it may be regarded as a sign that protein is probably insufficient.

Acknowledgment.

The senior author acknowledges, with thanks, the help received from Mr. N. C. Das Gupta, Assistant to the Physiological Chemist. Mr. Das Gupta carried out the analytical work and supervised the digestion experiments.

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PREFACE

During the past twenty years that the Chemical section of the Agricultural Research Institute, Punjab, has been functioning, a considerable number of investigations and analyses have been carried out on the Punjab soils. While these, with the exception of analyses undertaken during the past two years, have not fallen into any systematic scheme of investigation on the Punjab soils as a whole, and no comprehensive survey of these soils has been undertaken, it is proposed to present in the following paper the collected data which have accumulated from the investigations so far carried out, in the hope that they may give a skeleton outline of the more important soil features of the various districts of the Punjab and indicate some of their distinguishing characteristics.

AGRICULTURAL COLLEGE, LYALLPUR.

17th May, 1928.

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CONTENTS.

LIST OF ILLUSTRATIONS.

SOILS OF THE PUNJAB.

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1. Main Features of the Province.

Before attempting to describe the soils of the Province or give details of their chemical and physical composition, it is desirable to describe the main general features of the Province as these exercise no small influence in interpreting the figures of analysis and consequently the treatment which a soil may require.

(*a*) Physical and Geological Factors.

The Province falls into five main physical divisions :—(*a*) The Himalayan Region, (*b*) The Himalayan Sub-montane, (*c*) The Arid Plateaux of the Salt Range, (*d*) The Arid South-Western plains and (*e*) The western portions of the Indo-Gangetic plain.

Of these the first three are small in area and the first and third are not of great importance from an agricultural point of view ; the Sub-montane, however, is the most fertile and wealthiest in the Punjab. The remaining two divisions are of vast extent and fertile towards the South, where they encroach on the plains of Sind and Rajputana, and depend almost entirely on canal irrigation for their prosperity.

Geologically, the Punjab falls into three natural divisions :—The plains, the Salt Range and the Himalayas. The plains, which consist almost entirely of the Indo-Gangetic alluvium, form the chief subject of study in this paper. In the north of

the Province the Salt Range stretches from the Jhelum valley on the east to the Indus on the west, and crops up again beyond that river. The Himalayas form the eastern boundary of the Province, extending from the south-east to the extreme north.

(b) Meteorological Factors.

The Punjab being an inland Province, the climate over the greater part of it is of a most pronounced continental character, extreme summer heat alternating with great winter cold, but its diversified surface, including montane, sub-montane, and plain zones, very largely modifies the temperature, weather and climate in different parts of the Province. The Punjab may accordingly be divided into four natural divisions, in each of which the general meteorological conditions are believed to be fairly homogeneous (Diagram I).
These are :—

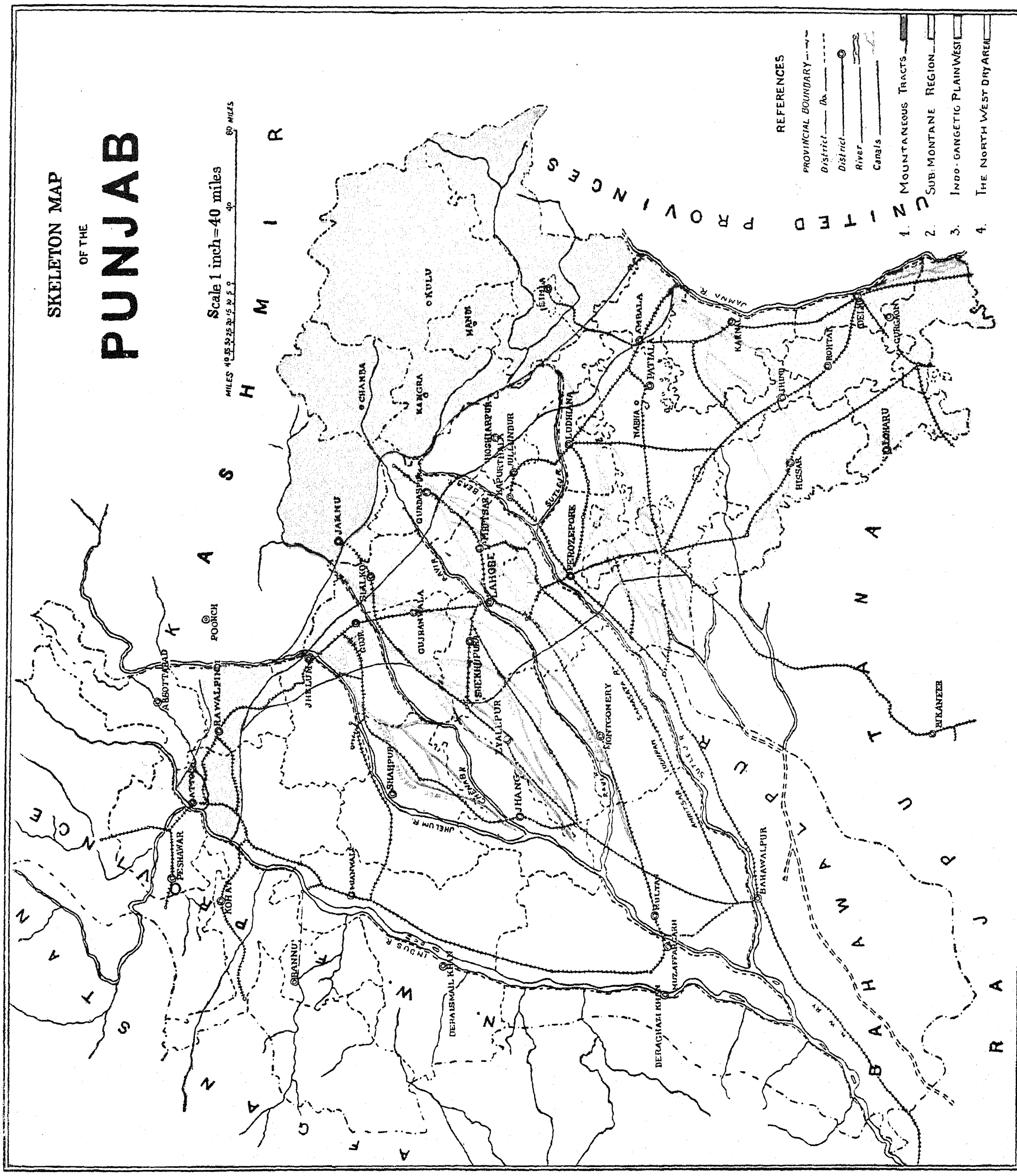
1. The Himalayan (*e.g.*, Simla and Murree).
2. The Sub-Himalayan (*e.g.*, Ambala, Ludhiana, Gurdaspur, Sialkot and Rawalpindi).
3. The Indo-Gangetic plain west (stations extending as far as Lahore).
4. The North-West dry area (stations Mianwali, Sindh Sagar, Muzafargarh, Dera Ghazi Khan and Multan, etc.).

Taken as a whole, the Punjab has in normal years two well defined rainy seasons. The first, or period of the north-east monsoon, extends from the end of December to the end of February or even upto the middle of March. During this period the Punjab experiences what are generally known as winter rains. The second period of rainfall, the result of the north-west monsoon, lasts from the end of June to the middle of September. The rainfall is naturally heaviest in the Himalayan and sub-montane regions, the highest average received being 126″ at Dharamsala, while the average for the region is nowhere less than 36″. In the plains the rainfall decreases rapidly as we pass from the hills. The sub-montane zone, which skirts the foot of the hills, and of which Rawalpindi, Gurdaspur and Sialkot may be taken as typical stations, has an average annual rainfall of 30″ to 40.″ The Eastern plains from Delhi to Lahore, belong to the West Indo-Gangetic plain, and have a mean rainfall of about 24″. To the west and south-west lies the dry area characterised by an extremely light and variable rainfall, and heat and dryness in the hot season, extreme even for the Punjab. The ordinary south-west monsoon winds from the Sindh and Kathiwar coasts encircle, but do not actually blow into this area, which therefore gets very little rain from this source, though it occasionally receives heavy cyclonic downpours from storms which have travelled westwards from the head of the Bay. Montgomery and Multan are typical stations of this tract.

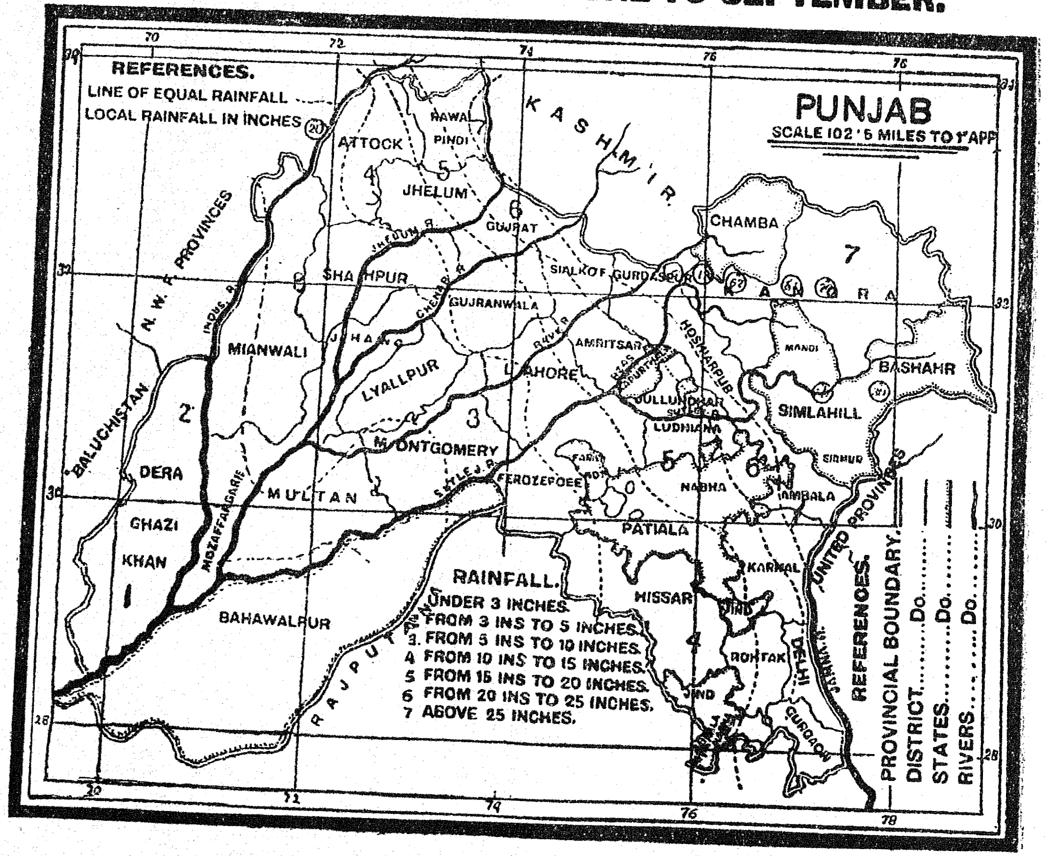
The amount of rainfall for different regions of the Punjab is represented in Maps A and B. The plains, owing to their arid nature and remoteness from the sea, are

DIAGRAM I.

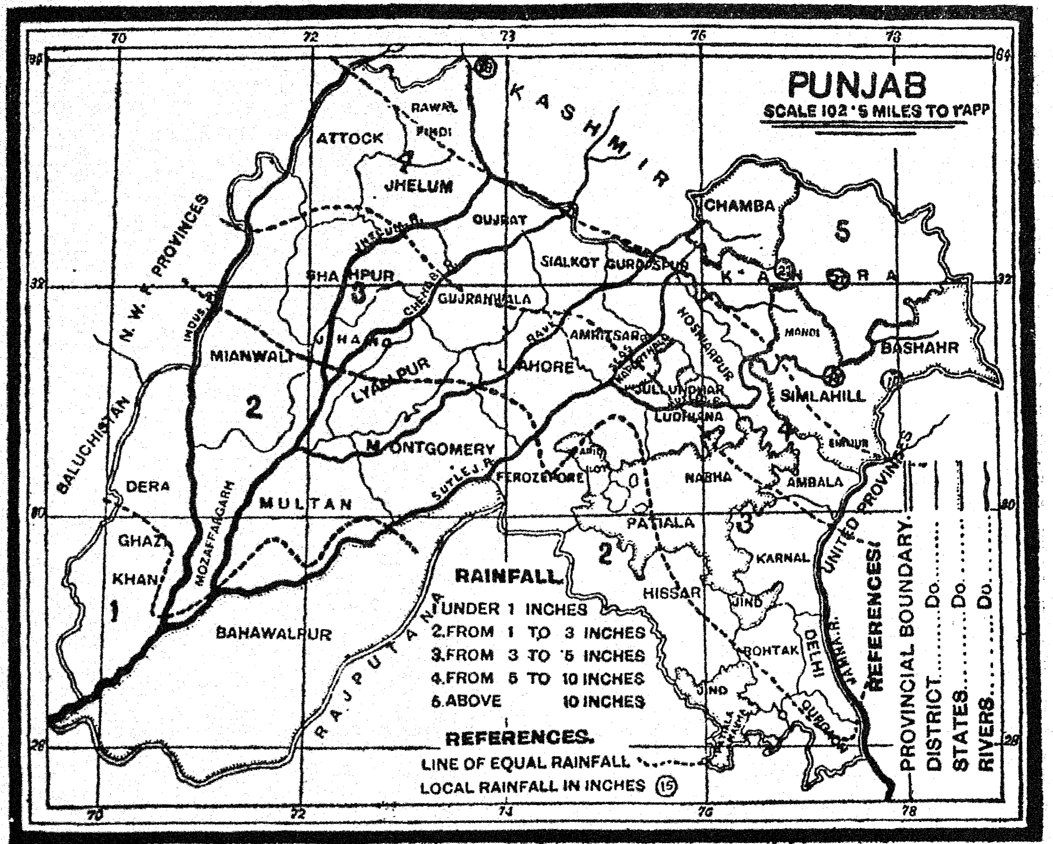
Showing, different Physical Divisions of the Punjab.



MAP A SHOWING AVERAGE RAINFALL IN INCHES IN THE PUNJAB IN THE MONTHS JUNE TO SEPTEMBER.



MAP B SHOWING AVERAGE RAINFALL IN INCHES IN THE PUNJAB IN THE MONTHS OCTOBER TO MAY



subject to extreme variations of climate. In winter the degree of cold is as intense as may be found anywhere in the plains of India. In the latter part of December and January and sometimes in February the night temperature commonly falls below freezing point, while by day the thermometer does not as a rule rise above 75°, and for four months of the year the Punjab climate with its bright sun and keen invigorating air cannot be surpassed. In summer, on the other hand, the fierce dry heat is exceeded only in Sindh. In June the thermometer commonly reaches 115°-121°, while the night temperature averages from 75°-90°.

(c) Artificial Irrigation.

The Punjab possesses the greatest irrigation system in the world. In the year 1926-27, out of a total cropped area of 30,406,941 acres, 13,941,456 acres were irrigated and of this area, 72 per cent. (10,048,746 acres) was served by canals, 408,580 acres by tanks and other sources of water supply, and 3,484,130 acres from wells (chiefly in the districts of Jullundur, Sialkot, Hoshiarpur, Gurgaon and Ludhiana). The canals of the Punjab are not lined, and owing to the velocity of the water carry fairly coarse silt. They are designed at a slope which causes slight silting in the *Kharif* when the rivers are in flood, and they scour to some extent in winter.

(d) Underground Water.

Particulars regarding the level of the sub soil water are given in the body of the paper with the description of the particular soils. Lately, on account of the construction of the big canal systems and consequent seepage, partly due to an interruption in the natural drainage at certain places, water has accumulated in the upper soil layers to such an extent as to cause water-logging. Consequently, such soils are going out of cultivation. Another effect of canal irrigation has been the rise of the subsoil water table at many places. For instance, in Lyallpur the water table is rising at the rate of one foot every four years. In the Lower Chenab, figures for a number of years show that the rise of the water level at certain places is $1\frac{1}{2}$ feet per annum.[1] In some parts the water table has already reached the surface and caused water-logging. The percentage of water-logged area on the Punjab canals is so far small—not more than 1 or 2 per cent.; but the serious aspect of the question lies in the fact that the rise of the water table is general throughout the Doabs, and there is no evidence so far of any slackening or reduction in this rate. There is no question whatever that when the water table gets within 10 feet of the surface in any tract, the future prosperity and productivity of that part is in a critical position. From this depth the rise of the water by surface tension and its evaporation from the surface becomes considerable. This goes on constantly, and 'Kallar' or Salts thus tend to accumulate in the upper soil layers.

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[1] Roberts, W; & Faulkner, O. T. A Text-Book of Punjab Agriculture, *Civil and Military Gazette Press*, Lahore, 1921.

On the other hand, in some districts such as Jullundur, the water level, owing to heavy demands on the wells, has been gradually falling during recent years.

(e) Agricultural Features and General Soil Conditions.

Excluding the Himalayas and other hill tracts and the Ravines of Rawalpindi, Attock, and Jhelum districts, the vast alluvial plain of the Punjab is broken only by the wide valleys of its rivers. Its soil, for the most part, is a sandy loam, interspersed with patches of clay (samples 199 and 226, Table I) and tracts of pure sand (samples 115 and 223, Table I). The soils of the Himalayas and lower ranges resemble those of the plains, but both sand and clay are rarer and the stony area is considerable.

The Punjab has two harvests :—The *rabi* (*Hari*) or spring, sown mostly in October-November and reaped in April-May ; and the *kharif* (*Sawani*) or autumn harvest sown in June—August, and reaped from early September to the end of December. Both sugarcane and cotton though sown earlier are autumn crops. With the development of irrigation the tendency has been for intensive cultivation in the *rabi* to replace the extensive cultivation of the *kharif*.

The principal spring or *rabi* crops are wheat, gram and barley. Wheat occupies a much larger area in the Punjab than any other crop, *viz.* 30 to 35 per cent. of the total cropped area. The actual area for the year 1926-27 was 9,379,462 acres. After wheat, gram is most extensively grown, covering about 4½ million acres, of which only 12 per cent. is irrigated. The largest areas are found in Ferozepur, Hissar and Rohtak. Should winter rains be favourable, wheat or barley gives a good yield ; whereas gram subsists best when the rainfall is less. The area under barley in the Punjab is rather over a million acres, *i.e.*, about 1-10th of the area under wheat, and the crop is chiefly grown in the districts of Hissar, Ferozepur and Gurgaon, mostly on light unirrigated land.

Of the autumn or *kharif* crops, rice, cotton and sugarcane are the most important. Rice is grown chiefly in the Kangra, Gurdaspur, Amritsar and Gujranwala districts. The plant grows best in a very heavy soil where plenty of water is available ; stagnant water is, however, unfavourable for its success.

The area under cotton has been liable to considerable variations in the last few years owing to the great fluctuations in price. In 1924-25, a record area of 2,326,335 acres was under cultivation. Excluding the montane and sub-montane areas, cotton is grown wherever irrigation is possible and the land not excessively sandy, cotton being almost exclusively an irrigated crop, in the Punjab.

The Punjab, amongst all the Indian Provinces, has the second largest area under sugarcane, usually varying between 3½ and 4½ lakhs of acres.* The best areas for the growth of the crop are in the south-east of the Province, in the districts of Rohtak and Karnal, the next best being the eastern districts such as Gurdaspur and Sialkot. The rainfall in the Punjab is nowhere sufficient for the growth of

* Lakh=100,000.

sugarcane, and thus this crop can only be grown either under irrigation or where, as near the beds of rivers, the underground water is sufficient. Cane can be grown profitably on land which is moderately heavy, but it is useless to try to grow it on very light soils.

Such, in brief, is the description of the chief physical features of the Province and we may now consider the main theme of our paper, *viz.*, the chemical and agricultural characteristics of different types of soil met with in different regions of the Province. These have been arranged according to the four general meteorological divisions given above.

2. The Himalayan Tract.

The Himalayan tract includes more than half the state of Jammu and Kashmir in the extreme north-west while the district of Kangra and the Simla hill states form the south-east part of the Punjab Himalayas; east of this lies the Kumaun division of the United Provinces, followed by Nepal, Sikkim, Bhutan, etc. In the Punjab we are concerned only with the Kangra and the Simla hills.

The Agricultural parts of the Himalayas with few exceptions are of secondary importance, to the plains the chief food grains cultivated in the outer ranges being rice, wheat, barley and maize. In the hot moist valleys, chillies, turmeric and ginger are grown. At higher levels potatoes have become an important crop, and in Kulu and Kumaun, fruits, such as apples, pears, cherries, plums and strawberries have been successfully naturalised. Two crops are obtained in the lower hills, but cultivation is attended by enormous difficulties, owing to the necessity of terracing and clearing land of stones, while irrigation is only practicable by the aid of long channels winding along the hill sides from the nearest suitable stream or spring. As the snowy ranges are approached, wheat and buck wheat, grown during the summer months, are the principal crops and only one harvest in the year can be obtained. Tea gardens were successfully established in Kumaun during the first half of the 19th century, but the most important of these are situated in Kangra.

1. Kangra.

With the exception of the examination of some samples from the district of Kangra, very little work has been done in connection with the montane tract of the Province. As mentioned above, the Kangra district is eminently suited for growing tea and fruits. Rice is also grown at many places in the district although it is not of superior quality, and the soils examined from this district have been confined to tea gardens only. Most of the tea gardens are situated in the valley at a height varying from 2,500 to 4,500, or even 5,000 feet in some cases. For at least six months in the year the climate is warm and moist and the rainfall is not less than 100 inches per annum, but even at these elevations the cold is never so severe as to injure the growth of the tea plant. Hot winds are unknown in the Kangra valley.

The analyses of some representative soils of the tea estates in this valley are given in Table I Nos. 1-7. It will be seen from an examination of these soil types that tea is being grown on a variety of soils. For example No. 1 is a light sandy loam ; Nos. 2, 6, and 7, medium to heavy loam ; while 3, 4 and 5 may be designated stiff clay soils. From a study of their chemical composition, however, it will be seen that with the exception of Nos. 1 and 4, the others are comparatively rich in nitrogen. The soils also appear to be rather deficient in lime, but are sufficiently alkaline to allow the conservation of a large proportion of combined nitrogen. Soils No. 2, 5, 6 and 7 are exceptionally rich in nitrogen and potash for tea soils. On the other hand, with the exception of soils Nos. 2 and 4, they are all below par in phosphoric acid and in this respect compare only with second grade Assam soils. Phosphoric acid is a manurial constituent of great importance in tea soils, since it not only serves to stimulate ripening but it also induces early development of the young plant and secures a sound establishment of the root system. A light dressing of crushed bone meal every now and then is likely to improve these soils considerably. The question of the magnesia content will be discussed separately later.

3. The Sub-Montane Tract.

The Sub-montane tract includes the districts of Ambala, Hoshiarpur, Gurdaspur, Sialkot, Rawalpindi and Attock. From the southern foot hills of the sub-Himalayas there extends a width of high level territory flanked by an outer ridge of recent formation known as Siwaliks—a line of broken and disintegrating hills which mark the first step upwards from the plains. The sub-montane tracts of the Punjab are enclosed between the Siwaliks and the Himalaya, and the upland valleys skirting these mountains include some of the most fertile and beautiful of the Indian low-land formation in the north-west.

The districts of Rawalpindi and Attock, situated on an undulating plateaux, comprise wide rolling plains broken by wild, irregular, and in the districts of Attock, mostly barren ravines and hills of very varying magnitude. There is no regular irrigation, and agriculture in these districts depends almost entirely on rain water which, except in some parts of Attock, is plentiful. The chief crops grown are wheat and barley, with *jowar* (*sorghum vulgare*), *bajra* (*Pennisetum typhoideum*), gram, and pulses in addition in the Rawalpindi district, and millet and maize in the Attock district.

The remaining districts present many points of similarity in their physical and agricultural condition. As already stated, they constitute one of the most fertile and richest tracts of the Punjab. The chief sources of irrigation are wells, natural streams and canals. These, coupled with an abundant rainfall, secure for the crops a plentiful supply of water. The chief crops are wheat, barley, maize and sugarcane. Cotton is grown in the Hoshiarpur districts to some extent ; but there is neither any cotton nor sugarcane worth mentioning in the Ambala district.

1. *Ambala.*

The main portion of this district is a plain which descends from the Siwalik hills towards the south-west. This plain is fertile, and mainly composed of alluvial loam, intercepted at intervals of a few miles by gulleys through which the hill torrents descend. It is also interespersed with blocks of stiff clay soil, which in years of scanty rainfall are unproductive, thus rendering the tracts where they occur liable to attacks of famine.

Sample No. 8 in Table I represents a sandy loam tract of the *barani* area of the same district. This soil is seldom manured and generally gives a yield of from 7 to 8 maunds of wheat ; 10 to 12 maunds of maize, or 3 to 4 maunds of cotton. The usual rotation practised is wheat-wheat, or wheat-maize, cotton. Sample No. 9 represents a soil on which only rice is grown, and whose sub-soil water is generally about 14 ft. below the surface.

Soils No. 10—14, are taken from the Military Dairy farm at Ambala Cantonment which encloses an area of about five hundred acres. No. 10, a heavy loam, is a representative of one of the best soils of the district and gives a very good crop of wheat averaging about 16 maunds per acre. No. 11 is a sample of sandy soil suitable for growing cotton and wheat ; No. 12 is a soil from a pasture land which grows under *barani* conditions very good crops of grasses, Anjan and Baru. No. 13 is a sample of sandy soil which yields good crops when manured, while No. 14 is suitable for the cultivation of barley and gram.

2. *Hoshiarpur.*

The district is divided into four Tahsils, *i.e.*, Hoshiarpur, Garhshankar, Dasuya and Una.

A peculiar feature of the district are the Chos or hill torrents, which rise in the hills below the watershed, leave them by a narrow outlet and widen on their way to the plains until they break up into a number of branches, thus spreading like a net work over the plains. At an earlier period the silt washed down from the Siwaliks must have formed an alluvial plain to their west and caused its fertility, but owing to the deforestation of those hills, the Chos have for a considerable time been destroying it. Dry in the rainless months, they become raging torrents after heavy rains, and, passing through the sandy belt which lies below the western slopes of the hills, they enter the plain, at first in fairly well defined channels, but finally spread over its surface and bury the cultivation under infertile sand.

The Siwalik hills, which form the back bone of the district, are composed for the most part of soft sand stone from which a belt of light sandy loam known as the *Kandi* tract, lying immediately at their foot, is formed. This soil requires frequent, but not too heavy, showers, and the tract is to a large extent overspread with shifting sand blown from the torrent beds. Lying parallel to this is a narrow belt, in which the loam is less mixed with sand, and this is in turn

followed by the exceptionally fertile *Sirwal* belt in which the water level is near the surface and the loam little mixed with sand except where affected by the hill torrents, and is of a texture which enables it to draw and retain the maximum of moisture. Garhshankar is a tract of clayey land, while north of Dasuya and beyond the range of Siwaliks denudation, is an area probably formed by the alluvium of the river *Beas* and one of the most fertile in the district. The soil of the Una valley is for the most part a good alluvial loam, specially fertile on the banks of the Sutlej.

Two samples of soil have been examined from the latter tract; the first, No. 15 in Table I was taken from the village Premgarh and appears to be very suitable for wheat. The second No. 16 was taken from the village Kamalpur and represents land generally put under sugarcane, the yields being about 20 maunds of wheat; and 40—50 maunds of *gur* per acre from the Katha variety of cane, known as Chan in the district.

Both these soils are irrigated from wells in which the water level is 28 ft. deep. The land is fairly well drained and the most common rotation practised is wheat, maize, *senji* (*Melilotus parviflora*), sugarcane (maize is manured in the rotation).

3. *Gurdaspur.*

Of the four Tehsils which comprise this district, the southern two, Batala and Gurdaspur, are situated between the Bias and the Ravi rivers and present the ordinary features common to the sub-montane tracts of the Province. The tehsil of Pathankot towards the north of Gurdaspur is the most varied part of the district, containing as it does the low foot hills, outlying spurs of the foot hills, the valley, and the plains. The Tehsil of Shakargarh includes land which is somewhat different from the rest of the district, most of the land in this tehsil being very fertile, highly cultivated, with a somewhat higher sub-soil water level.

A marked feature of the Bari Doab is the existance of numerous *Chambs* or Swamps, the most noted of which is the *Khanuan Chambh*. We had occasion to examine the soil from Keshopur Chambh near Gurdaspur, the analysis of which is given later.

Nos. 17—21 and 48—53 of Table I represent samples taken from the Gurdaspur and Pathankot tehsils, whereas samples 22—27 were taken from a field on the Government Agricultural Farm, which was under manurial experiments for sugarcane, and 28—33 are representative samples of soils which have proved to be more suitable for growing sugarcane in the Gurdaspur and Batala tehsils.

Of the first five samples, No. 17 was taken from a typical rice field of the Pathankot tehsil; No. 18 from a typical rice field of the Gurdaspur tehsil, No. 19 from the sugarcane growing tract; No. 20 from a field which grows very good wheat and No. 21 represents a soil which appears to be suitable only for inferior crops such as *mash* (*Phaseolus radiatus*) and *moth* (*Phaseolus aconitifolius*).

Nos. 34—46 show analyses of some other soils from the district, while No. 47 is from a plot under green manuring experiments at the Government Agricultural Farm. Samples No. 48 and 49 are soil and sub-soil samples from fields A-1(*a*) on the farm. This soil, a rich loam, has been yielding good crops without any manure, the rotation followed being maize, *senji*, sugarcane. No. 50 and 51 are specimens of soil from Keshopur Chambh, a low lying piece of land about 2 to 3 thousand acres in extent, which grows luxuriant crops of grass such as *dubh*,[1] *chimbar*,[2] *palwanh*,[3] *siru*,[4] *pannih*,[5] *kahi*,[6] *nari*,[7] and *khabbal*,[8] etc., which, however, are available only for a period of about 3 months from August to October. The surface soil of the Chambh is a sandy loam, but on descending to the second foot, one meets with a stiffer soil, which probably accounts for the impervious nature of the land. Very good crop of rice were reported to have been raised from this tract some years ago. The land, however, has deteriorated in recent years, partly owing to the appearance of 'Kallar,' a condition due in some measure perhaps to the natural drainage in the middle of the tract having ceased to function.

Nos. 52 and 53 are samples of soils from the village of Jandoal on the Pathankot-Dalhousie road near Chakki. This soil, a medium loam, normally grows maize but is not suitable for other crops.

4. *Rawalpindi.*

This district may be divided into three main portions based on its more prominent features :—

1. The montanous portion consisting of the Murree Tehsil and the northern portion of the Kahuta Tehsil.
2. The hilly and sub-montane tract, including the spurs of the Margalla range, the area lying at the foot of the Murree hills, and the steep hills on the western bank of the Jhelum and the Rawalpindi Tehsil.
3. The plains, or Pothwar portion, including the whole of the Gujar Khan, the south-east portions of the Rawalpindi Tehsil, and the south-west portions of the Kahuta Tehsils.

Samples No. 54—59 were taken from the Military Dairy Farm at Rawalpindi which may be considered representative of the most fertile spots in the whole district. The farm consists of an undulatory piece of land with fields worked out in terraces, the soil of which consists chiefly of a reddish stiff clay. Samples No. 54 and 55 are from block 2 on the farm and represent a medium silt soil ; the rota-

[1] *Eragrostis Cynosuroides.*
[2] *Eleusine Flagellifera.*
[3] *Andropogon Pertusus.*
[4] *Imperata Arundinacea.*
[5] *Andropogon Muricatus.*
[6] *Saccharum Spontaneum.*
[7] *Paspalum Distichum.*
[8] *Cynodon Dactylon*

tion followed is *jowar*, barley, wheat-*jowar*-fallow. Samples No. 56 and 57 (block 3) represent a clayey loam, well suited for growing crops such as, *jowar*, wheat and barley. Samples No. 58 and 59 (block 2 sandy portion) are typical of the sandy soils, the rotation followed being *jowar-jowar*.

5. *Attock.*

The Attock district comprises the western portions of the rough plain country lying between the Indus and the Jhelum rivers, and under the mountains of Hazara. The district is divided into four Tehsils, *i.e.*, Attock, Talagang, Pindi Gheb, Fateh Jang, administrative divisions which correspond fairly closely with the natural divisions. The Attock Tehsil, though not itself homogeneous in nature, differs somewhat from the rest of the district, and may be divided into three main portions, *viz.*, the *Chhachh* plain, the most fertile and richest portion of the district; the *Sarwala* tract a desert of waterless sand, and the *Nala* tract, a level plain dotted here and there with barren hills and crossed by ravines. The Talagang Tehsil consists of a high lying plateau, scoured by the deep beds of numerous torrents and fettered everywhere by innumerable small gullies and ravines. The Fateh Jang tehsil comprises the country lying between, and on both sides of the *Sil* and *Swan* streams. North of the Sil the high lands ascend in a wilderness of irregular ravines scoured by torrents. The valley of the Swan consists of the broad and sandy bed of the streams flanked by wide stretches of rich alluvial loams, while beyond the Swan is the less fertile land known as *Wadala*, which, on its southern side, comprises the country known as Asgham, a narrow undulating plain of small villages with light fertile soil and good *barani* cultivation. The south-west corner of the Pindi Gheb Tehsil is a wild and mountainous country where cultivation is carried on either in the sandy soil found on the top of the stony plateau or in deep valleys, banked up at their lower ends in order to arrest the soil washed down by the floods. The remaining portion of the central plateau known as the *Jandal*, is a tract, the characteristic features of which are undulating stretches of fine sandy soil pre-eminently suitable for gram crops. The rest of the Tehsil consists of high open country, mostly barren and unproductive, but containing here and there more fertile depressions. Towards the east at Fatehjang, the country is a bleak, dry, undulating, often stony tract, broken by ravines and pitted by outcrops of rock.

Thus the district consists of high mountain tops, bleak and unfertile, in the main, but with very fertile spots at intervals, low lying valleys, and vast level plains; in fact all the various types of physical configuration possible are met with, and any wide uniformity of soil type in such a tract is not to be expected. The soil types met with are residual and cumulose, culluvial and alluvial and even loess, in fact almost all possible soil types are to be seen. In places, the hard rocks may be seen in the process of disintegration and present a very instructive study in methods of soil formation.

In Table I are included analyses of 31 samples of soil, taken from different villages in the Fatehjang Tehsil, with the exception of Khunda which is in the Pindi Gheb Tehsil. The country covered by most of these soils is a part of the Nala tract, a level plain, dotted with barren hills and streaked with ravines and streams. Analysis confirms our expectation that the soils from such a tract do not fit in in any orderly scheme of soil types. The figures are given as indicative of the different types of soil met with in the locality south of the Kala Chitta range. The soils examined were mostly taken from the Fatehjang Tehsil and only three samples representing the first three feet were taken from the village Khunda in Pindi Gheb Tehsil, and one sample of black surface soil from the same village. The soils from the different villages were all taken from a three foot column, each foot being kept separate. The soils from Ajjuwala (Nos. 63—65) are the heaviest of all the samples examined. As one travels from the village towards the south-west, the soil gradually changes from a light medium soil at Kharala Khurd (Nos. 66—68) to a sandy soil at Khunda (87—90), and a similar variation in the mechanical composition is noticeable as we move towards the north-east to Jhang (69—74) and Neka (75—80). The soils from Fatehjang-Sadkal (Nos. 60—62) and Doian (84—86) are all light medium soils. All the soils in the Fatehjang Tehsil and also those in the Pindi Gheb Tehsil a little further to the left hand side of the Rawalpindi-Kohat Railway line are light medium soils, while those on the right hand become gradually heavier as we travel from Rawalpindi to Gagan, a distance of about 30 miles. These remarks are, however, based upon the assumption—which as the physical description of the district given above shows may not always be correct—that the soils from any one village are typical of a considerable area surrounding that village.

The popular belief as to the clayey nature of these Ajjuwala soils is confirmed by mechanical analysis; but the soil samples examined from Khunda which are popularly regarded as similar in type to the Ajjuwala soils are sandy and not clayey. In fact, out of all the samples examined these are the only soils which are typically sandy. The soil from Fatehjang-Sadkal are shown by mechanical analysis to be heavy medium soils from which Kankar is absent and not sandy as commonly believed. All the other soils from the villages Kharala-Khurd, Jhang, Neka, and Qutbal (81--83), known as lime stone or *kankar* soils, are medium or light medium soils.

The Lime and Lime-Magnesia ratio.

The figures for these (average for a three feet column) are given below.

The popularly known *kankar* and lime stone soils from the villages Kharala Khurd, Neka, Qutbal and Doian, have all a high lime content varying from 8 per cent. to 13 per cent., and all of them, with the exception of the soils from Kharala Khurd, have an equally high lime-magnesia ratio. Of all the soils examined, those from Kharala Khurd show the highest figures for magnesium as far as the third

foot. Consequently, their lime-magnesia ratio is much less than that of the other soils referred to above.

Village	Lime	Lime : Magnesia	Physical classification
	per cent.		
Sadkal	1·97	1·70	Heavy medium.
Ajjuwala	12·86	7·97	Clay.
Kharala Khurd	7·86	3·41	Light medium.
Jhang (irrigated)	5·73	2·87	Medium.
Jhang (*Barani*)	4·45	2·98	Do.
Neka (irrigated)	8·91	7·33	Light medium.
Neka (*Barani*)	10·01	8·61	Ditto.
Qutbal	11·84	7·15	Ditto.
Doian	13·21	8·37	Ditto.
Khunda	5·77	3·38	Sandy.
Khunda (black soil)	3·44	1·64	Ditto.

It is remarkable that the "Limestone soils" from Jhang do not contain as much lime as the lime and *kankar* soils from other places. A still more remarkable fact is the very high percentage of lime found in the clayey soils of Ajjuwala. This should have modified favourably and to a very large extent, the hard, impermeable character of the soil making it as good a producer of crops as any normal soil, yet the crops grown at the time when the samples were taken presented a very poor appearance. But, as mentioned in the physical description of the district, much depends upon the character of the rocky substratum.

Iron.

The quantity of iron present in these soils is not very high and does not vary very much, with the exception of the Neka soils which contain somewhat less iron. This excludes any explanation as to the red colour of the soil being due to the high proportion of iron present. The white soils from Kharala Khurd contain more iron than the black soils from Khunda.

All the soils are rich in potash and are certainly not deficient in phosphates, when we take into consideration the fact that most of the Punjab soils have a P_2O_5 content lying between 0·1 and 0·2 per cent.

Nitrogen.

The amount of nitrogen present in these soils compares favourably with that found in most of the Punjab soils, the average 0·066 per cent. being slightly higher than the average for the latter. Even the second and the third foot columns contain 0·055 per cent. nitrogen.

The figures for "Loss on ignition" which are usually taken to represent roughly the amount of organic matter present in any soil, are high when compared with other Punjab soils.

These soils, as revealed by chemical analysis, are not deficient in any of the essential plant food ingredients, yet they are not so fertile as other Punjab soils. Perhaps this is due to the fact that these soils lack the necessary plant food material in the available form.

The figures for the amount of total solids (Table II) present in the water extract of these soils are much higher than we ordinarily meet with in the alluvial soils of the Punjab. This coupled with the fact that all these soils contain on an average 0·2 per cent. of sodium bicarbonate may explain to a certain extent their lesser fertility as compared with rich soils in other parts of the Punjab.

4. The Indo-Gangetic plain.

The Peninsula of India is separated from the northern area of upheaval, of which the Himalayas are the southern revetment, by a broad interval of low flat country known as the Indo-Gangetic depression, which extends from the delta of the Ganges to the delta of the Indus. Since the geological era in which occurred the parting of waters, when the Indus first started westwards and the Ganges turned its currents to the east, the physical character of the two basins has rapidly diverged.

In the Punjab the Indo-Gangetic plain extends westwards as far as Lahore. The whole of the Gangetic basin is within the influence of the south-west monsoon rains, and those portions of the Punjab plain which represent an extension of the Gangetic basin are benefited by these rains. The western tracts, however, which form the basin of the Indus and its affluents, present physicl characteristics differing in many essentials from those of the Gangetic basin proper. From the districts where the plains spread southwards, the Punjab presents the picture of a flat treeless landscape except in the areas served by the canals. There was a time when forests grew in the Sind valley, but they have long ago disappeared and it is probable that with this disappearance the meteorological conditions of the Indus valley have greatly changed.

No part of the Indus valley is subject to a regular and systematic rainfall in the monsoon season, although the fall gradually increases from Sind towards Lahore. Thus the climate of the valley is hot and dry. Irrigation has, however, greatly developed lately and there are green areas around the Indus river and the newly

spread net work of the Punjab canals, which are once again altering the character of the landscape.

Wheat, barley, gram, cotton and sugarcane are the chief crops grown in the plains area, the latter two predominating in the eastern parts.

1. *Hissar.*

This district falls into four natural divisions :—

A. *The Rohi tract*, of the Sirsa Tehsil which stretches from the northern boundary to the Ghagar, whose soil is a soft reddish loam, interspersed with sand and clay, the water level in the wells of which varies from 40 to 180 ft. in depth.

B. *The Nali tract*, stretching from east to west through the Fatehabad and Sirsa Tehsils. Its characteristic feature is a hard iron clay soil, which permits of no cultivation unless well saturated with water.

C. *The Bagar tract* stretches from the south and west of Sirsa through Sirsa, Fatehabad, Hissar and Bhiwani. Here the prevailing features are a light sandy soil with shifting sand hills interspersed in parts with firmer and even loamy bottoms ; the spring level is more than 100ft. below the surface and the water is frequently bitter.

D. *The Hariana tract* comprises the whole of the Hansi, and the eastern portions of the Fatehabad, Hissar and Bhiwani Tehsils and is traversed by the Jamna canal. The leading feature of the tract is its firm clay soil ; sand hills are occasionally found, but the low lying parts are particularly hard and clayey. The spring level is generally below 100 ft. except in canal villages where it rises to within 30 to 40 ft. of the surface.

Samples 91 to 96 and 105 to 109 were taken from the Government Agricultural Farm at Hansi and may be taken as representative of the Hariana tract.

No. 91 is a good average soil and contains a small proportion of *kankar*. In wet weather water remains standing on the surface and in times of draught the crops suffer. The rotation generally followed is wheat-cotton-sugarcane, the average yields being respectively 25, 3, and 40 maunds (of *gur* in the latter case). Sugarcane is manured at the rate of 15 tons of farmyard manure per acre.

No. 92 is a good loam very well drained and is generally put under the rotation, cotton, *juar*, with manure to cotton only. The average yields obtained are 10 maunds of cotton and 10 maunds of *Juar* (*Sorghum vulgare*).

No. 93 is of the same type as No. 92. The rotation followed is wheat, cotton, *senji* (*Melilotus parviflora*) without the use of any manure, and the average yields per acre are, wheat 30 maunds and cotton 12 maunds.

No. 94 is a somewhat poorer soil of average type and contains a very small amount of *kankar*.

Nothing but cotton was grown in this field and no manures were used. The average yield of cotton obtained was 6 maunds per acre.

No. 95 is of the same type as No. 94 except that this soil was from a permanent wheat plot where no manure was used and the average yield of wheat grain per acre was 15 maunds.

No. 96 is a very heavy soil fit for growing rice only, and was rather impermeable to water. No manures were used and the yield of rice averages 15 maunds.

Soils Nos. 105 to 107 have an almost similar chemical and mechanical composition. No. 105, however, was taken from a field which was developing *kallar* and hence is not suitable for growing normal crops; still, barley and fodder crops do quite well in this soil. No. 106 is a sample of soil from a piece of land which was under the rotation wheat, *toria*, cotton, and represents one of the best soils on the farm. The average yield during the last five years has been 23 maunds per acre of wheat, *toria* 6 maunds and cotton 9 maunds. No. 107 is a sample of soil from grass land on the farm. Samples 108 and 109 are from a plot which was under wheat.

Samples No. 97 to 100 are from the Hissar cattle farm. Hissar may be said to represent the Bagar tract of the district although some of its area falls in the Hariana tract. The sample examined contains a high percentage of clay, but the presence of a considerable quantity of fine sand imparts to these soils the characteristics of a sandy loam. The soil represented by Nos. 99 and 100 are coarser grained than the others and more suitable for wheat, oats and barley. This soil, however, produces good crops of sugarcane and *chari*, when manured.

Samples 101 and 102 represent soil and sub-soil samples respectively from permanent rice fields in the village of Rasulpur (Tehsil Sirsa) and are representative of the soil in that locality. The soil as the mechanical analysis shows is a hard, clayey soil containing 25 per cent. of clay. Nos. 103 and 104 are soil samples from the village Sikandarpur of the same Tehsil which is suitable for growing sugarcane, maize, potatoes and vegetables.

One remarkable feature common to all the soils from Hissar is that their lime content is higher than that of any others of the district, while in regard to the other constituents they are similar to soils from Hansi and Sirsa. Correspondingly, the lime and magnesia ratio is high, in fact, higher than in any of the average soil samples from Hansi, Hissar or Sirsa.

There is one noteworthy feature about the two soils from Sirsa, their lime content is about the same, but magnesium in the soil from Rasulpur is about three times that found in the Sikandarpur sample. This difference reflects itself in the lime magnesia ratio, which becomes 2·23 the highest for any of the soils examined so far in the entire district. At present there seems to be no explanation for this difference; no doubt the soil from Sikandarpur is sandy and that from Rasulpur a heavy medium type, but we do not get lower figures for magnesia in sandy soils as a general rule.

2. *Karnal.*

The soils in this district are of a very diverse character varying from fertile loams to stiff clays which are covered with dense thickets of *Dhak* (*Lutea Frundosa*).

A great portion of the land in the district is watered by the western Jamna canal, while floods from the Saraswati and other streams are helpful in raising crops such as gram from the area commanded by them. The figures for two samples of soil from the well irrigated areas of the district are given under Nos. 110 and 111 of Table I. Sample No. 110 was taken from a plot in Samalkha and is best suited for growing wheat. This soil, with sub-soil water 13 ft. below the surface, is very well drained, and yields on an average 20—25 maunds of wheat per acre. The general rotation practised is wheat, sugarcane, wheat. Sugarcane is generally manured at the rate of 20 cart loads of farmyard manure per acre, but wheat is seldom manured. The yield of sugarcane is 40 to 50 maunds of *gur* from the Suretha and Lalri varieties. Sample No. 111 was taken from the village Manana, where sugarcane is the chief crop grown, yielding an average of 50 maunds of *gur* per acre. The rotation followed is sugarcane, wheat, cotton, *senji*. Both sugarcane and cotton are manured, the former at 20—25 cart loads per acre and the latter at 12—15 cart loads only. The new varieties of sugarcane such as Co. 205, 223 and 213 are now giving much higher yields, *viz.*, about 80 maunds of *gur* per acre. The soil is good and well drained and carries a hard clay substratum at about the 7th foot, while the depth of the sub-soil water is about 19 ft. Other analyses of soil samples received from the Deputy Commissioner of the Karnal district in the year 1914 are given under Nos. 112-118.

Nos. 119—124 are samples of surface soils and sub-soils from the Imperial Cattle Breeding Farm, Karnal, having been taken respectively from plots Nos. 3, 4 and 5. No. 125 is from plot No. 2. As will be seen from the analysis, the soil of the farm is a light medium loam, and, as experience has shown, gives a very good crop of wheat, the average yield being 20—25 maunds. These soils can with proper manure and irrigation be made to yield very good crops of sugarcane, the climatic conditions for which are very suitable, owing to the absence of frost.

3. *Ferozepur.*

This district consists of a flat alluvial plain well wooded in its northern half, but very bare in the south where it is absolutely without hill or eminence of any description and devoid of rock and stone.

Wheat and gram are the most important crops, rice and maize being grown on the inundation canals, while *Moth* (*Phaseolus aconitifolius*) is the chief crop of the sandy tracts. Little sugarcane or cotton is grown. A large portion of the district has recently come under irrigation, by waters from the Sutlej valley canal projects.

Sample No. 126 in Table I was obtained from a tract commanded by both inundation canals and well irrigation in Ferozepur Tehsil. Water percolates with

difficulty and on drying the land becomes rather hard. It is usually put under wheat and gives an average outturn of 20 maunds per acre. The spring level is generally about 10 ft. from the surface.

Sample 127 was obtained from a village, Sada Singhwala in the Moga Tehsil, whose land is irrigated by canal water and is generally put under gram, although a study of its physical constituents and chemical analysis indicates that it is suitable for more paying crops.

Samples Nos. 128—131 were obtained from the Military Dairy Farm, Ferozepur cantonment and represent light medium soils quite well suited for growing sugarcane, wheat and gram. Nos. 128 and 129 are the surface soil and sub-soil samples from plots 5, 6 and 7 on the farm which are under wheat, gram, barley and oats. Samples Nos. 130 and 131 represent soil from plots 3 and 4 which is not so sandy and grows maize, *chari*, barley and lucern.

4. *Jullundur.*

This district forms an irregular triangle with its base on the river Sutlej. No hill or rock breaks the monotony of the plain which forms a zone of rich cultivable soil skirting the foot of the Himalayas and was regarded by the Sikhs (before the present canal system came into existence) as the garden of the Punjab. Sandy patches are found at places, and with these few exceptions one vast sheet of luxuriant and varied vegetation spreads over the plain from end to end. A complete failure of the rains seldom occurs, and, assisted by the protection afforded by the numerous wells, the soil is on the whole sufficiently charged with moisture to resist minor attacks of drought. A large portion of the district consists of good alluvial loam; though patches of clay and sandy soils also exist. Tracts are also known which contain a considerable quantity of large nodules of *kankar* in the sub-soil layers.

The only analyses available are from samples obtained from Rahon, near the eastern corner of the district. Samples 132 and 133 in Table I show the analysis of these soils. No. 132 was taken from a light soil, while sample 133 represents a very fertile heavy loam. The chief sources of irrigation are wells and flood water from the river. The average yields of crops from these heavy soils per acre are:—wheat 15 maunds, cotton 5 maunds, maize 12 maunds, and rice over 20 maunds. In the absence of irrigation facilities, the sandy soils are seldom put under crops.

No. 133 is the heaviest fertile soil in the Province we have met with. The average rainfall in the locality is 20 to 30 inches and it is quite probable that such a soil, if situated in arid tracts like that of Multan or Muzaffargarh, might prove to be quite uncultivable and unfertile. This is an illustration of the fact that climate and locality very largely determine the properties and character of any soil.

5. *Lahore.*

The Lahore district presents an almost uniform level surface from end to end, with hardly any variety in its physical features. Its soil is inclined to be dry, but

in parts near the Amritsar border good sandy loams are met with. The well waters specially in the tract between Patti, Kasoor, Raewind and Kana Kachha are inclined to be saline.

Two samples of soil from this tract are on record. No. 135 in Table I was taken from a village named Jodhu in the Lahore Tehsil. It is a very good soil, well drained, and is generally put under a heavy cropping system, the chief rotation followed being wheat cotton *senji*-sugarcane.

Sample No. 136 was taken from the District Board farm at Raewind and is fairly representative of the saline tract mentioned above. The soil is very fertile and grows good crops of wheat, maize and sugarcane. The sub-soil water is generally at a depth of about 20 ft.

6. *Sheikhupura.*

This district is a new one having been until quite recently a part of the Lahore, Gujranwala, Sialkot and Lyallpur districts.

Most of the land in the district is irrigated by the Upper Chenab Canal and the Lower Chenab Canal, and on account of seepage of water from these canals, a vast tract of land near Chichoki Mallian has become waterlogged and consequently unfit for cultivation. Rice is the chief crop grown in the greater part of the district.

The eastern tracts of the district have another source of irrigation in the river Degh which, rising in the Jammu hills and flowing through the districts of Sialkot and Gujranwala, enters Sheikhupura district at its extreme north-eastern border near Sadhoke and continues for most of its course to flow parallel to the eastern boundary of the district. At Tappiala it branches into two portions, one portion borders the large village Kot Pindi Dass and the other Kuthiala and Khanpur. The latter branch is called the chhoti Degh. They again join near the village Dhenga and after flowing for some miles further, the stream falls into the Ravi. The Degh is most uncertain in its supply of water, being principally dependent on the rain from the hills. At times, however, the stream descends with great rapidity, and its waters overflow the country for miles on either sides. In the hot weather it is nearly, but very rarely, quite dry. Above the village of Uderi the water has to be raised by Jhalars of Persian wheels, but below it irrigation can be effected by the natural flow of the water. The deposit left by the flow is rich and the best rice is grown on lands which have been submerged by it.

No. 137 in Table I is a sample of a very good soil which generally gives an outturn of 15—20 maunds of wheat, 6—9 maunds of cotton, 30—40 maunds of sugarcane (*gur*) and 12 to 15 maunds of *toria* (*Brassica Napus*).

No. 138 is a sample from a soil which represents a fair average of the tract. The average yields obtained on this tract of land are from 12—15 maunds of wheat, 5—6 maunds of cotton, and 8—10 maunds of *toria*. Sugarcane is seldom grown.

Samples Nos. 139 to 150 are from different types of soils but all growing wheat under different conditions of irrigation; these being recent canal irrigation, old

canal irrigation, *barani* and well irrigation. Each successive set of 3 soils representing sandy, loam and clay, being under the above mentioned four types of different irrigations respectively. A glance at the figures of analyses will show that no correlation appears to exist between the chemical analayses and any particular type of soil.

The water level is generally 27 to 30 ft. from the surface.

7. *Gujrat.*

The Northern corner of this district is crossed by the Pubbi hills, a low range forming a continuation of the salt range and pierced by the Jhelum at Mung Rasul. Immediately below and surrounding these hills, a high sub-montane tract extends across the north of the district from the Jhelum eastward. But the greater part of the district lies on the Indo-Gangetic alluvium. The sub-montane portion consists of a good firm soil of reddish colour with an admixture of sand. The portion in the plains, however, consists of a rich reddish loam.

Samples Nos. 150, 151, 152 were obtained from Chillianwala and represent soils which are chiefly suited for sugarcane, gram and rice respectively.

5. The North-West dry area.

1. *Montgomery.*

This district occupies a great part of the tract known as the Ganji Bar.

The land in the two Tehsils, Montogomery and Okara, with the exception of a small tract near Kamalia, is irrigated by the Lower Bari Doab canal, while the Depalpur and the Pakpattan Tehsils are irrigated by water from inundation canals supplemented by water from wells. During the next few years, however, it is expected that the whole of the district will come under irrigation from the Sutlej valley project and the proposed extension of the Lower Chenab Canal. The soils of the district comprises some very good loams and also some very hard soils quite unfit for cultivation. Soils impregnated with soda and other salts are not uncommon.

The Agricultural Department possesses an experimental farm at Harrappa where the problem of reclaiming *bara* soil is under investigation. Some description of these inferior soils will be given later. Confining attention for the moment to the good soils in Table I, samples 153—157 represent specimens of normal soils of the district. Cultivation of these lands has been of a very recent introduction (the canal having been opened as recently as 1914) and they are capable of producing very successful crops of American cotton, *Desi* cotton, wheat, sugarcane, *toria* and maize.

Samples Nos. 158—162 are from the Coleyana Estate, Okara. Nos. 158 to 161, from squares 25, 26, 43 and 45 respectively, are specimens of good sandy soils suit-

able for lucerne and *oats*, but equally suitable for growing charree, shaftal and other cereal crops. No. 162 is a sandy soil approaching a medium loam, and is one of the best soils on the estate.

Soils Nos. 163 to 166 are from the Agricultural Department's old Seed Farm, and 167 to 172 from the new Seed Farm. Nos. 163 and 164 are the soil and sub-soil samples from square 17, line 1, and 165 and166 from square 15, line 3. On the basis of their mechanical analysis, both these soils (Nos. 163 and 165) belong to the group of sandy soils; but since almost all the sand present is fine sand, the soils approach the medium loam type which is suitable for growing almost all crops. The 6 samples, Nos. 167—172, are the soil and sub-soil samples from square 15 field 11, square 28 field 1 and square 12 field 25 on the new seed farm. The first of these resembles in texture soil Nos. 163 and 164 above, while the last is a light medium soil.

2. *Lyallpur.*

The district was constituted in 1904, mainly from villages transferred from Jhang, with the addition of a certain number from Montgomery. It comprises most of the high table land between the Chenab and the Ravi rivers and is now irrigated by the Lower Chenab canal. The climate is very hot in the hot season and the rainfall very low, *viz.*, about 12 inches. The sub-soil water is very low, about 58 ft., but has been steadily rising in recent years. The soil is a fine loam, except in the Toba Tek Singh Tehsil where it becomes sandy towards the west.

From 8 to 10 ft. below the surface, the sub-soil is extremely sandy, hence the soil is very well drained and water percolates with considerable ease. The water level is about 60 ft. from the surface and has risen about 3 ft. during the last ten years.

Several borings have been made extending to the sub-soil water level in connection with work on the movement of moisture in the Lyallpur soils. Table III shows the figures for the mechanical analysis of each successive 2 ft. column of soil. A glance at the figures obtained from these borings will show how very sandy are the lower strata of the sub-soils in the Lyallpur district.

Other analyses of soil samples obtained from the Government Agricultural Farm at Lyallpur and other parts of the district are presented in numbers 174 to 185 of Table I. Nos. 182 to 185 are surface soil and sub-soil samples from square 10 and 29 respectively on the Lyallpur Agricultural farm. Both these soils are sandy, the former being a comparatively poor soil having been under various crops, such as barley, wheat, oats, during the last five years. The latter represents soil from the Botanical garden which has been found to be very well suited for growing citrus trees, mangoes, dates and other fruits.

No. 173 may be considered to represent a typical soil of the district. From an inspection of the analyses of other samples, it will be seen that the soils of this district are of a distinctly sandy nature, lacking in humus, but successfully produc-

ing cotton, wheat, sugarcane, *toria*. maize, vegetables and fodder crops. The chief rotations followed are :—

1. wheat, wheat-*toria*, cotton.
2. wheat, cotton, wheat.
3. maize, *senji*, sugarcane, wheat.
4. wheat, *chari* and *guara*, gram, cotton.

The average yield for these crops are :—

Wheat :—16 maunds, *toria* 8 maunds, cotton 8 maunds, maize 16 maunds, *senji* (green) 250 maunds, gram 20 maunds, sugarcane 50 maunds (*gur*), *chari* and *guara* (green) 300 maunds.

Oranges, lemons and maltas have also done particularly well.

It has been estimated that alkali land to the extent of about 175 square miles exists in this district representing, from absence of cultivation, a loss of about Rs. 100,000 annually in revenue alone.

3. *Shahpur*.

With the exception of that portion of the salt range which is included in the north of the Khushab Tehsil, the whole of this district forms part of the great Indo-Gangetic plain.

In the valleys of the Jhelum and the Chenab, and in the plain between, the soil for the most part is a very fertile sandy loam interspersed with patches of clay and sand. The portion covered by the Thal consists chiefly of sand hills with occasional patches of hard level soil and tracts of ground inpregnated with salt on which practically nothing grows.

In Table I, Nos. 186, 187, 188, 190 to 196, and 206 to 213 were obtained from the Sargodha Remount Depot, soil No. 186 being particularly good for growing wheat ; cotton does best on No. 187, and No. 188 responds very well to sugarcane. In fact, Nos. 187 and 188 would, under the circumstances, grow good crops of wheat, cotton, sugarcane, maize and *toria*.

Soil No. 189 is from the Camel Corps Farm, Sargodha, and is deficient in nitrogen and phosphates. The analyses shows that soils Nos. 190 to 196, reported as poor, are not deficient in plant food but require proper cultivation. No. 194 is, however, calcareous and poor in phosphoric acid.

Samples Nos. 206 to 213 represent the surface soil and sub-soil samples from 4 different places on the farm. Samples 206 and 207 are specimens of a light medium soil from square 366, under the rotation, *chari*, fallow, linseed and oats. Samples 208 and 209 are from square 207, a type of medium soil bordering on heavy loam. This is the heaviest soil on the farm and one of the best as far as yield is concerned. The rotation generally followed is berseem, oats and lucerne, sugarcane, wheat and cotton ; in fact, all kinds of crops should do equally well. Samples 210 and 211 are from square 64 and represent a light sandy soil suitable for growing gram,

barley, etc. The rotation followed has been gram, barley, (*Guara* as green manure), barley and *chari*. The last two samples from the farm are from permanent grass plots used for grazing and making hay and represent a medium silt soil, one of the best types of soil from an agricultural point of view.

Samples Nos. 197 to 205 were taken from the Remount Depot, Mona and represent all the different types of soil met with on the Depot area. Soils Nos. 197 and 198 are the surface soil and sub-soil samples from square 72 which comprises a medium silt soil capable of growing oats, barley and citrus fruits, etc. The rotation actually followed on the area is, *chari*, fallow, lobia, fallow, oats, fallow. Soils Nos. 199 and 200 are specimens of a medium soil with a high percentage of clay but considerably modified by the presence of a considerable admixture of sand. The area has been kept under grass, but the soil is of a quality such as to be well suited for wheat, oats, *chari*, lobia, etc. In samples 201 and 202 (square 33) we have a light sandy soil which should do quite well for *moth*, barley, gram, etc. Samples 203 and 204 (square 125) represent a soil similar to that of Nos. 197 and 198. It should grow all the crops for which the previous soil is suitable; as a matter of fact, it is used as a permanent grass paddock. Soil No. 205 is the first foot sample from square 165 which is under lucerne.

4. *Jhang.*

The district is divided into 3 portions, *viz.*—

(*a*) *The tract lying toward the east of the Chenab River.*

The soil here is an alluvial loam more or less mixed with sand, and, on the whole, extremely fertile, and is commanded by the Lower Chenab Canal.

(*b*) *The Tract lying between the Chenab and the Jhelum.*

This is irrigated by the Lower Jhelum Canal and the soil is generally good except that in many places it is impregnated with salt and therefore unfit for cultivation.

(*c*) *The portion lying west of the Jhelum.*

This is a portion of the famous tract known as the Thal. The Great Indian Desert, which borders the whole southern limit of the province sends out two arms which embrace the actual country of the five rivers. That on the east takes in a great part of the Phulkian state, with its apex near the town of Ludhiana. The western arm (locally known as the Thal) extends from the Sind border up the Indus valley to the south-west angle of the salt range. The eastern chain of sand-hills and alternating barriers has of late, however, lost much of its desert character through canal extensions. The Thal which constitutes the great Stappe in the Sind Sagar Doab, consists of a series of rolling sand-hills formed by the wind, which

run parallel to the great barrier formed by the salt range and are broken by valleys in which the original surface is exposed. In some of the eastern parts of the Thal the sand hills are very high, in others the ground is perfectly level for miles. A scanty rainfall, a treeless sandy soil, and a precarious and scattered pasturage mark this out as the most desolate tract now remaining in the Punjab. Much of it is real desert, barren and lifeless, and devoid not only of bird and animal life but almost of vegetation.

Nos. 214 and 215 in Table I show the analyses of samples of soils from a village, Bagh, in the canal irrigated tracts of the district. Containing as they do an excess of coarse and fine silt, they form very good soils for crops such as wheat and cotton.

5. *Multan.*

The Multan district is almost entirely encircled by the confluent streams of the Chenab and the Jhelum which unite at its south-western extremity. The soil of the district is of a uniform alluvial nature, with sand everywhere at a greater or less depth from the surface. From an agricultural point of view, the district may be regarded as composed of 3 distinct tracts :—

(*a*) The riverain tract.

(*b*) The tract irrigated by the Lower Bari Doab canal and the inundation canals and wells.

(*c*) The *Bara* (unirrigated).

In Table I, sample No. 216 represents a soil from the tract irrigated by the inundation canals and wells, while sample No. 217 represents a good soil from the area covered by the Lower Bari Doab canal. Analyses of samples from other parts of the district are given under Nos. 218—229, of the same table.

6. *Muzaffargarh.*

This district occupies the southern area of the Sindh Sagar Doab. The wild Thal of the Doab extends as far as the middle of the district and occupies more than half of its area. A brief description of the characteristics of the Thal has already been given.

Of the remaining land, that lying alongside the two rivers is subject to heavy floods, but the central portion is protected by embankments and is within easy reach of irrigation facilities. This portion accordingly is rich and productive and many large and prosperous villages are to be found in it.

Samples Nos. 230 and 231 in Table I have been taken from the irrigated tracts of the district where irrigation conditions are favourable. Most of the soils, of which sample No. 230 is typical, are put under rice. Otherwise, the soils taken as a whole also produce very good crops of wheat and cotton. Lately, however, considerable attention has been paid by the Zamindars to the development of fruit trees such as the date palm, mangoes, pomegranates, etc., and it is hoped that in

the near future this portion of the Muzaffargarh district will be more particularly devoted to fruit growing, specially the date palm, for which, owing to the saline nature of the soil, it is better suited.

Salt incrustations are common in the Muzaffargarh Tehsil.

7. *Dehra Ghazi Khan.*

This district is situated to the west of the Indus. On the north side it is mountainous, but the greater part of the district lies on the alluvium of the plains.

The soil varies from a rich loam to an alluvial clay as we pass from the mountains to the Indus. The chief sources of irrigation are the inundation canal from the Indus, and hill torrents which also deposit large quantities of silt, thus adding to the fertility of the soil.

Sample No. 232 in Table No. I was taken from a village named Churatta. The land is well drained and has a sub-soil layer which is very sandy. The chief rotation followed is wheat. *chari*, or wheat, cotton, and an average outturn of 10 maunds of wheat and 5 maunds of cotton per acre is obtained.

Samples No. 233 was taken from a village named Paigan. This and the village Churatta are both situated in the area irrigated by inundation canals and wells.

This land is considerably better than that represented by No. 232 and usually yields a crop of about 12 to 15 maunds of wheat and 5 to 6 maunds of cotton in a rotation of wheat followed by cotton.

6. The Mechanical Analyses.

Table I gives the results of the mechanical analyses of 139 surface soils and 54 sub-soil samples representing most of the districts of the Punjab. These results are represented on diagrams 2—7 which are drawn in accordance with Wilsdon's modification of the American system [1 and 2]. A glance at diagram 2 shows that most of the Punjab soils examined fall within the area represented by sandy loams and medium loams, although a fair proportion are clay loams. There are very few samples representing clay, sand and silt soils. Thus the majority of the Punjab soils tend to fall into groups (described by Hall as light loams and heavy loams), which, so far as the mechanical composition is concerned, are ideally good soils for cultivation, being good loams, sufficiently retentive of moisture and not difficult to work, and which should produce any type of crop provided proper manure is given. The general inclination of the Punjab soils is towards light sandy soils (medium soils) rather than clays, and as such they are one of the best types from the points of view of soil aeration, cultivation, and other factors so necessary for

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[1] Whittles, C. L. A note on the classification of soils on the basis of mechanical analysis. *Journ. Agri. Science,* Vol. XII. Pt. 2.

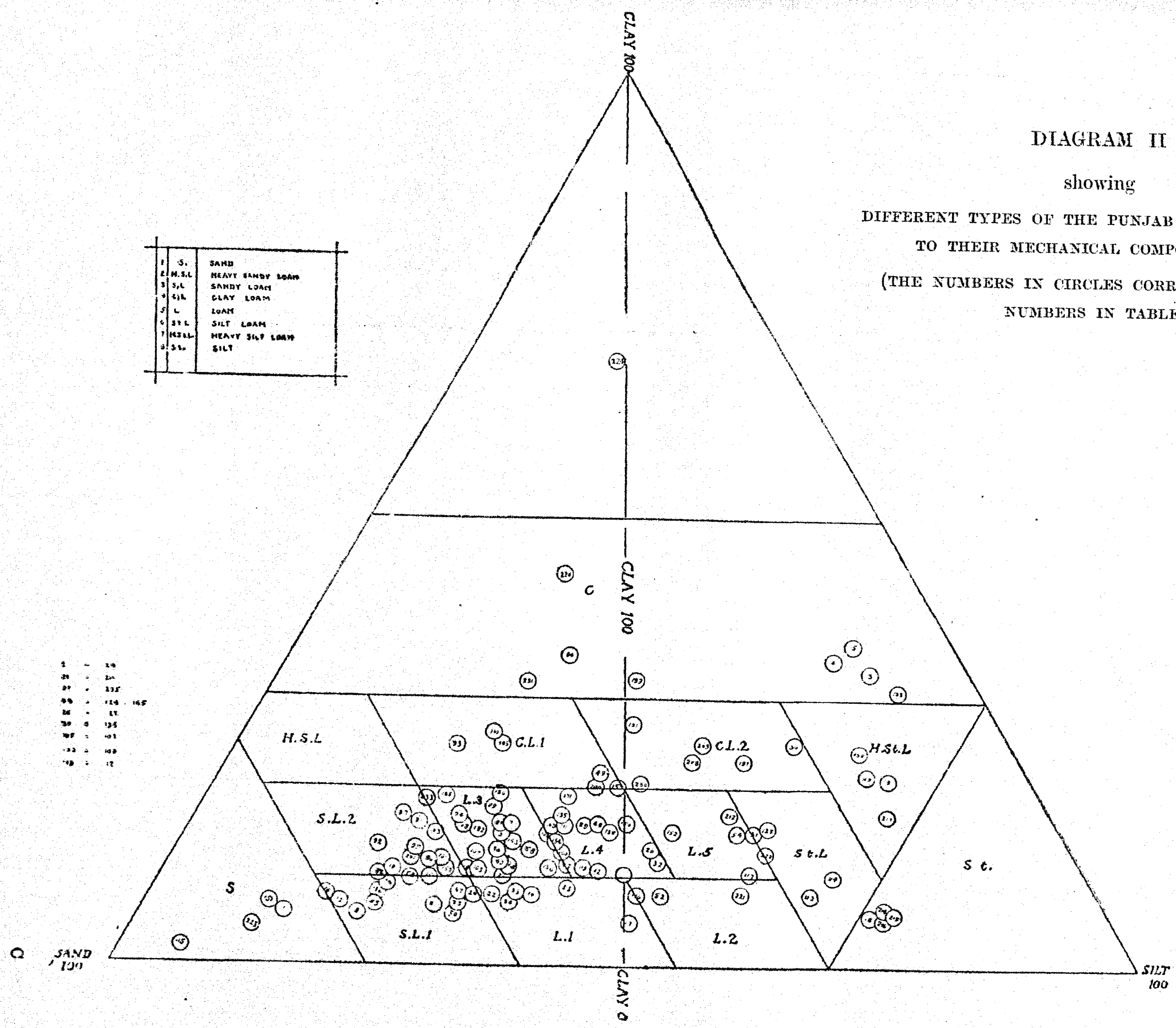
[2] Wilsdon, B. H. The need and objects of a soil survey in the Punjab. *Agric. Jour. India,* Vol. XIV, Pt. II, 1919.

DIAGRAM II

showing

DIFFERENT TYPES OF THE PUNJAB SOILS ACCORDING TO THEIR MECHANICAL COMPOSITION

(THE NUMBERS IN CIRCLES CORRESPOND TO THE NUMBERS IN TABLE I)



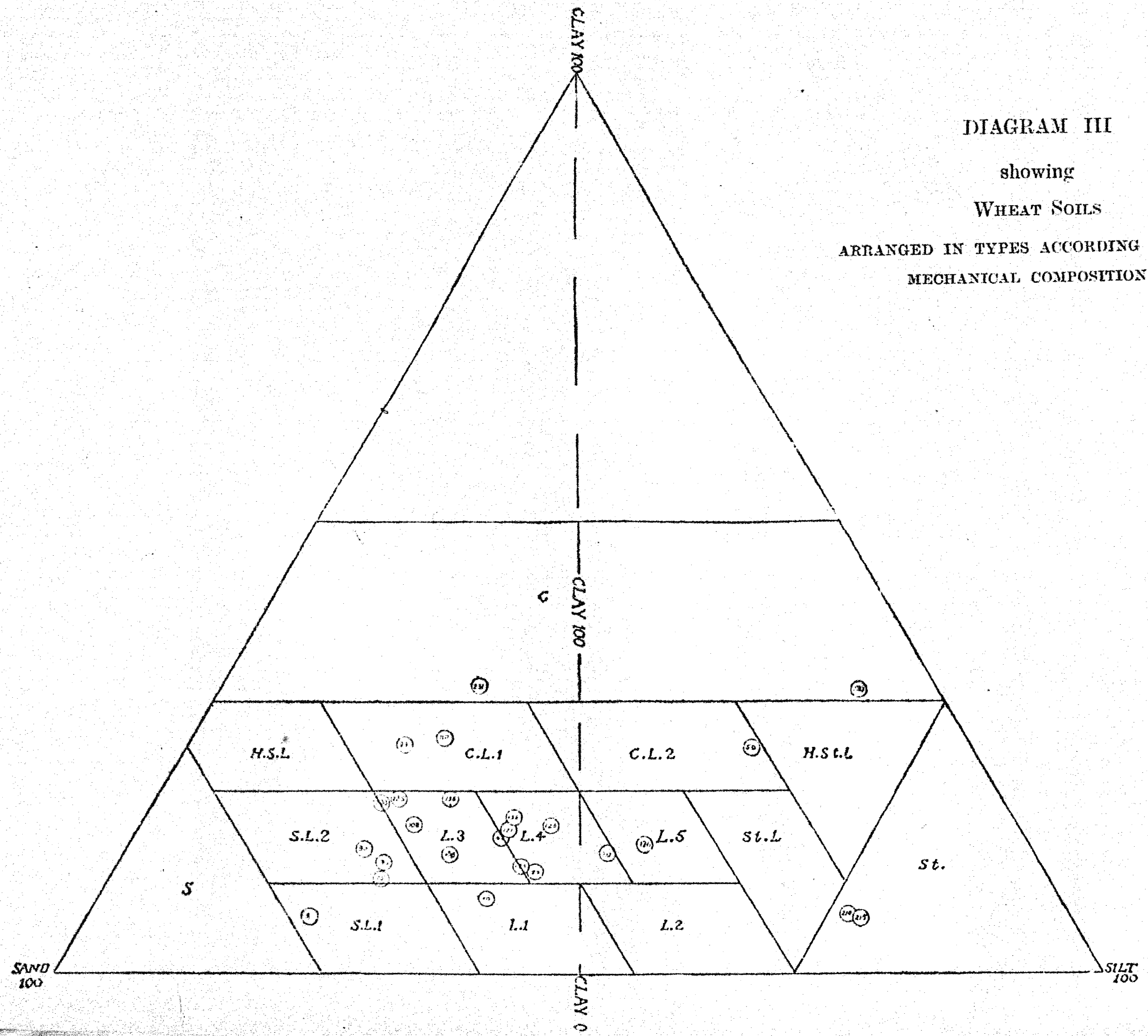


DIAGRAM III

showing

WHEAT SOILS

ARRANGED IN TYPES ACCORDING TO THEIR MECHANICAL COMPOSITION

DIAGRAM IV

showing

Cotton Soils

ARRANGED IN TYPES ACCORDING TO THEIR MECHANICAL COMPOSITION

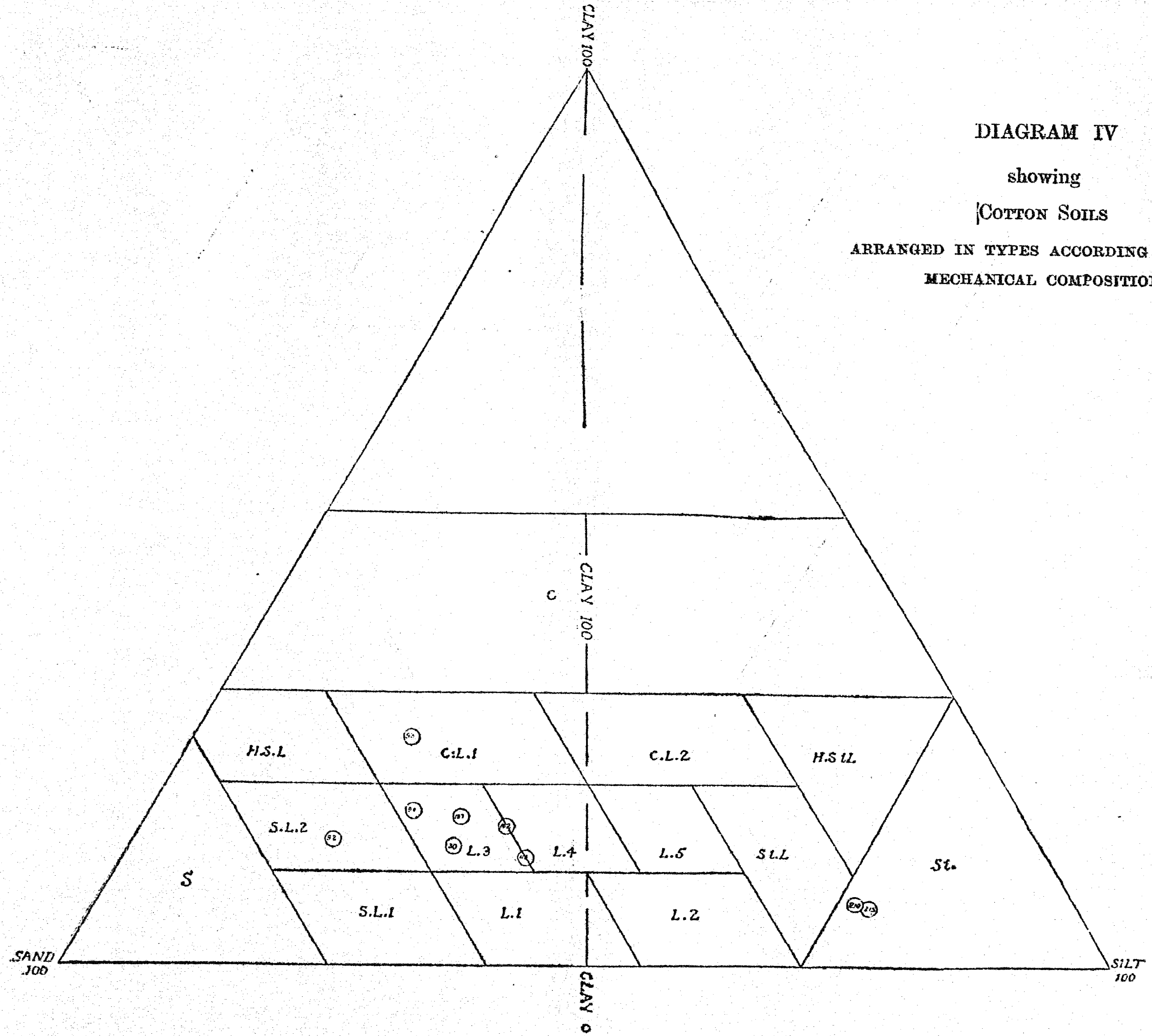


DIAGRAM V

showing

SUGAR CANE SOILS

ARRANGED IN TYPES ACCORDING TO THEIR MECHANICAL COMPOSITION

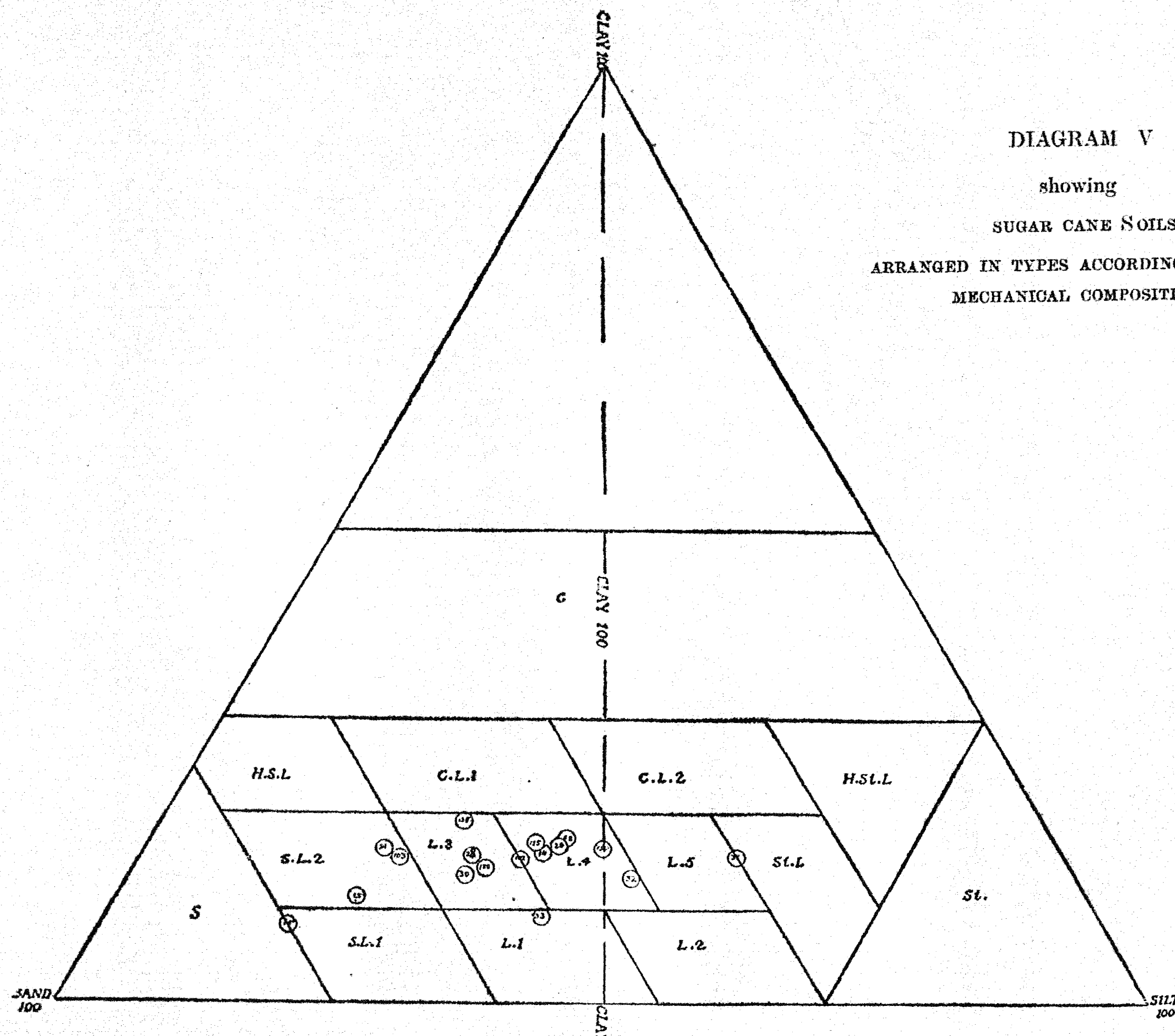


DIAGRAM VI

showing

Rice Soils

ARRANGED IN TYPES ACCORDING TO THEIR MECHANICAL COMPOSITION

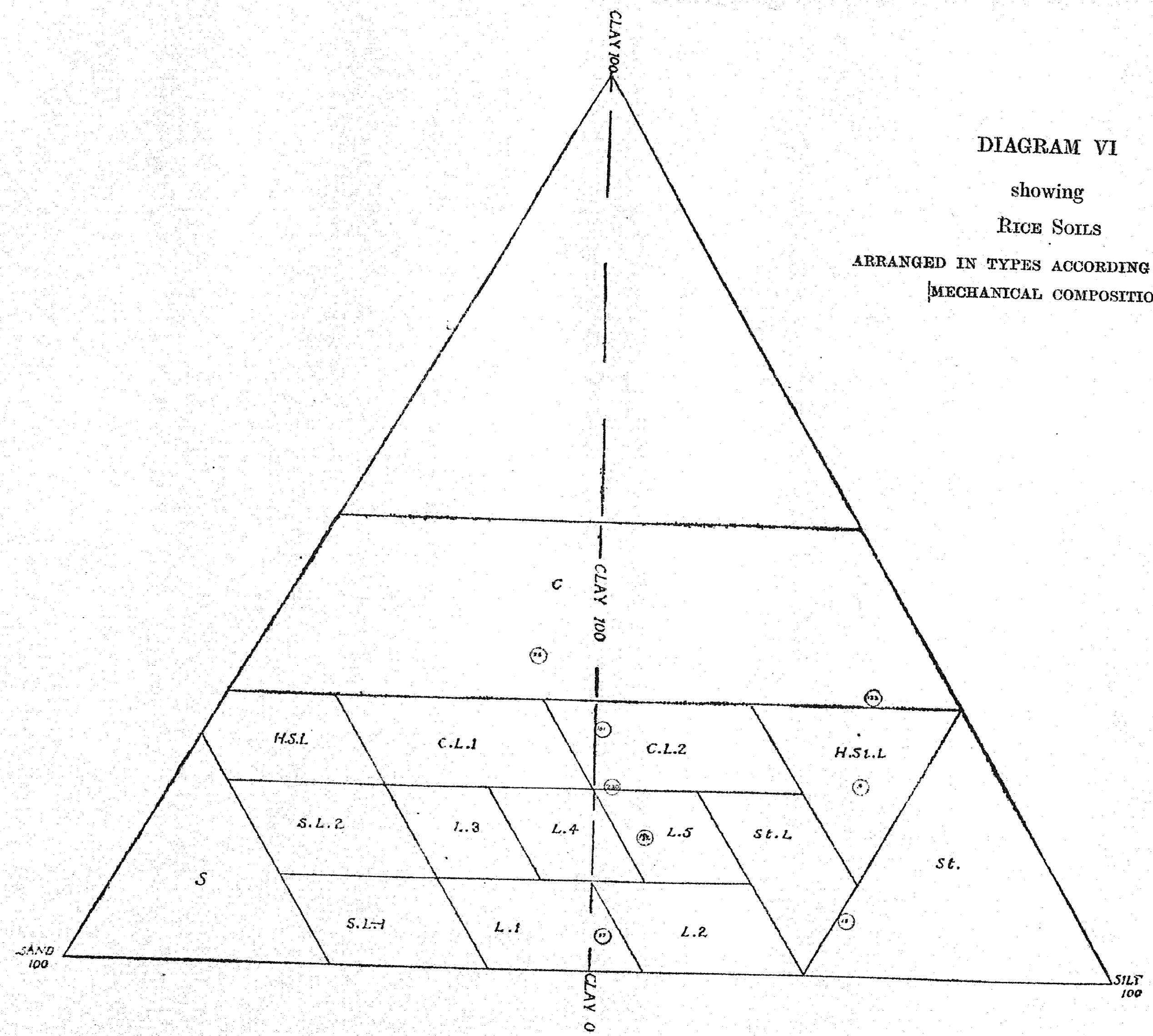
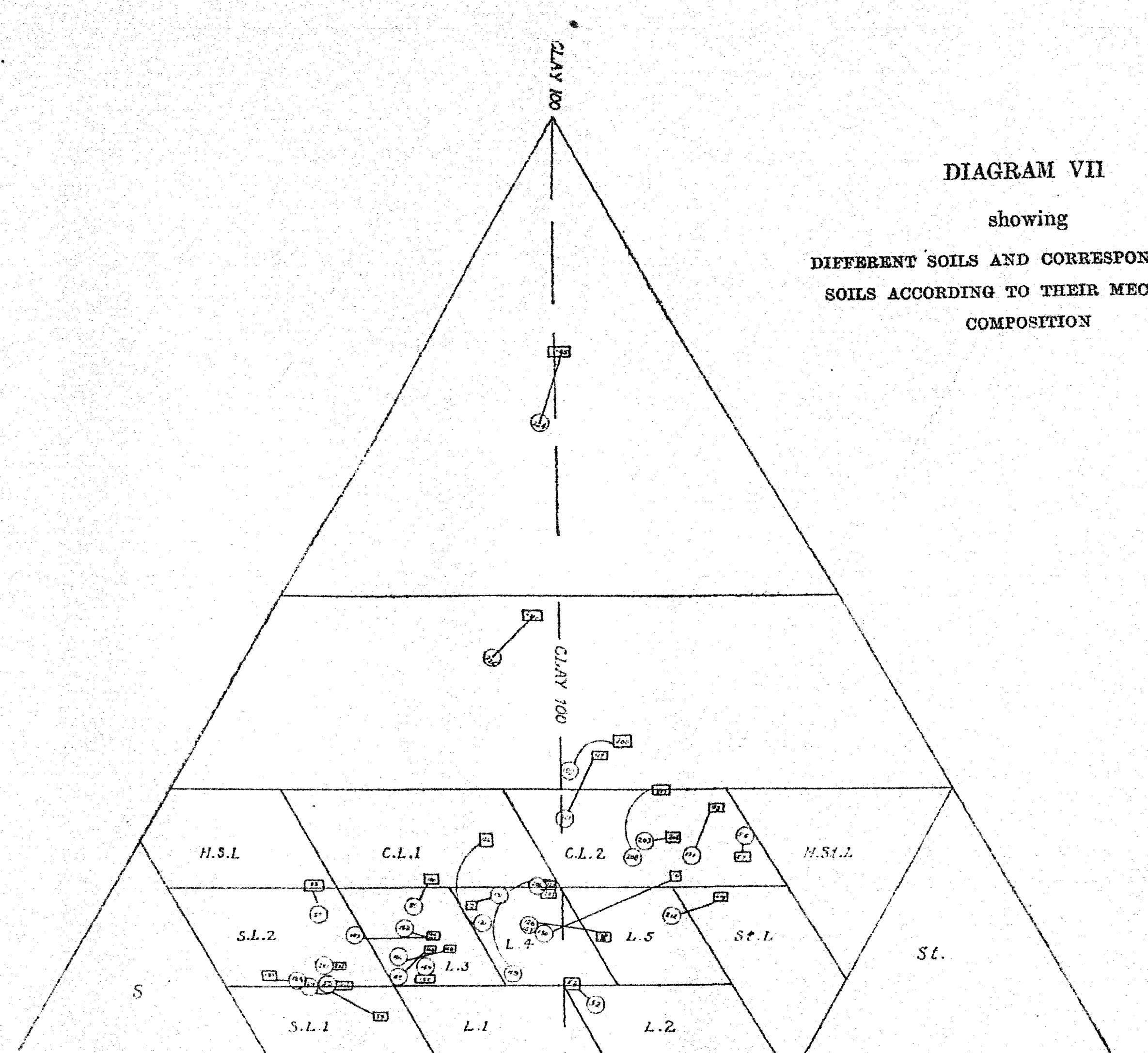


DIAGRAM VII

showing

DIFFERENT SOILS AND CORRESPONDING SUB SOILS ACCORDING TO THEIR MECHANICAL COMPOSITION



successful farming. Most of the soils have a clay content lying between 10 per cent. and 20 per cent. although quite a large number are known with a clay content much less than this—in some cases as low as 2-3 per cent. and sand as high as 70—80 per cent. It might appear that these latter soils are unfit for profitable farming, but as already mentioned the mechanical texture of a soil must also be considered in terms of rainfall, water supply, organic matter present, and other factors. A soil of a certain mechanical texture behaving as a loose sandy soil in a district with deficient rainfall (say in Multan or Muzaffargarh) may behave as a loam in a district with a medium rainfall, and as a heavy loam in a district with a heavy rainfall (*e.g.*, Kangra). Soil No. 1 from Kangra, for instance, is a sandy soil and Nos. 3 and 4 clay soils, but all of them are very good tea garden soils. A reference to the map showing the rainfall of the Province will demonstrate that most of these soils are quite suitable for profitable cultivation in districts such as Ambala, Hoshiarpur, Jullundur, Gurdaspur, Kangra and Simla. With plenty of organic material available, these sandy loams can readily be made to produce very profitable crops.[1]

At the two extreme ends of the scale we have samples Nos. 1 and 225. The first one is a sample of a sandy soil from Kangra containing only 6 per cent. of clay and 14 per cent. of silt, while the second one represents the heaviest soil so far net with containing 70 per cent. clay. These two samples demonstrate the effect of sand and clay on soils when these are present in abnormally high quantities. While it is possible, by suitable means, to raise crops from sandy soils, it is hopeless to expect any very good results from soils containing 50 per cent. or more of clay. Soil No. 1 grows a very good crop of tea, while soils Nos. 224 and 225 are unsuitable for growing even grass; nothing but sparsely scattered, dry parched shrubs grow upon these.

7. The Chemical Analysis.

I. *Nitrogen.*

Before attempting to discuss the nitrogen figures presented in Tables I and IV, it may be pointed out that experiments have been in progress both in the field and in the Laboratory at Lyallpur to find out the amount of nitrogen fixed in the soil and the factors that are responsible for the fixation. The results obtained have already been published [2], [3], [4], [5] and from them it will be seen that soils in

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[1] Lander, P. E.; Wilsdon, B. H.; & Mehta, M. L. A study of the factors operative in the value of green manure. *Agri. Res. Institute, Pusa, Bull.* 149, 1923.

[2] Lander, P. E. The Experimental Sullage Farm, Lyallpur, Bull. No. 157, *Agri. Research Institute, Pusa.*

[3] Lander, P. E. Report on the operations of the Dept. of Agriculture, Punjab, for the year ending 30th June 1923, Part I, pp. XX.

[4] Lander, P. E., and Barkat Ali. Nitrogen fixation in the Punjab. *Memoirs of the Dept. of Agri., Pusa, India, Bact. Series* Vol. II, No. I, 1925.

[5] Wilsdon, B. H., and Barkat Ali. Nitrogen fixation in the Punjab. *Soil Science,* Vol. XIV, 1922, No. 2.

the Punjab are capable of fixing nitrogen very rapidly and to as high an extent as 75 per cent. or in certain cases even 100 to 200 per cent., although losses to the extent of 25 to 40 per cent. due to denitrification have also been found. The largest and most frequent losses have been found to take place in the month of August, and this is confirmed by the results given in the report on the sullage farm at Lyallpur. From the curve presented in this report, it will be seen that in the month of August there is a loss of nitrogen to the extent of 600 lb. per acre. At Rothamsted samples of soil were taken every two hours for the estimation of nitrogen and it was found that something approximating 80 lb. of nitrogen was fixed in a single day but subsequently lost in the evening. It would appear therefore that the time of taking samples of soil for analysis will very greatly influence the amount of nitrogen found and in discussing nitrogen figures it is important to keep these fluctuations in mind.

From the data presented in Table IV, it will be clear that the nitrogen content of the Punjab soils, with very few exceptions, falls within the limits of 0·025 per cent. and 0·100 per cent. although most of the soils presented have a figure higher than 0·04, the average of 166 samples being 0·06 per cent. Figures as low as 0·01 (No. 115) and as high as 0·16 (No. 133) may also be noticed. The nitrogen content of the sub soils is slightly lower, the average figure being 0·05 per cent. A reference to the literature on the soils of the Hancock County of the U. S. A. and of Kent and Sussex in England [1], [2], will show that the nitrogen content varies from 0·15 to 0·45 in the soils of Kent and Sussex and from 0·10 to 0·25 in the soils of the Hancock County. This means that the Punjab soils are 50 to 200 per cent. poorer in nitrogen than those of the above-mentioned countries, although most of the soils of the southern states of the United States of America fall within the same range of nitrogen content as do the Punjab soils.

2. *Organic Matter* (*Loss on ignition*).

The Punjab soils taken as a whole are deficient in organic matter. The average of 120 samples works out to 3·75 per cent., while figures as high as 10 per cent. or even more are given by certain soils, *viz.*, from Attock. Most of the Punjab soils contain 2 to 4 per cent. of organic matter. Similar figures for soils from Kent, Sussex and North Wales[3] lie between 2·62 to 14·21 per cent., while for American soils they lie between 2·6 to 9·27 per cent.[4] The red river valley (America) soil contains no less than 26·3 per cent. organic matter.

In Table IV the ratios of the nitrogen content to the loss on ignition of the majority of soils in the Punjab are given. It will be observed that with very few

[1] Smith, R. S. Hancock County Soils. *Soil Report* No. 27. Agricultural Experimental Station, Illinois University.

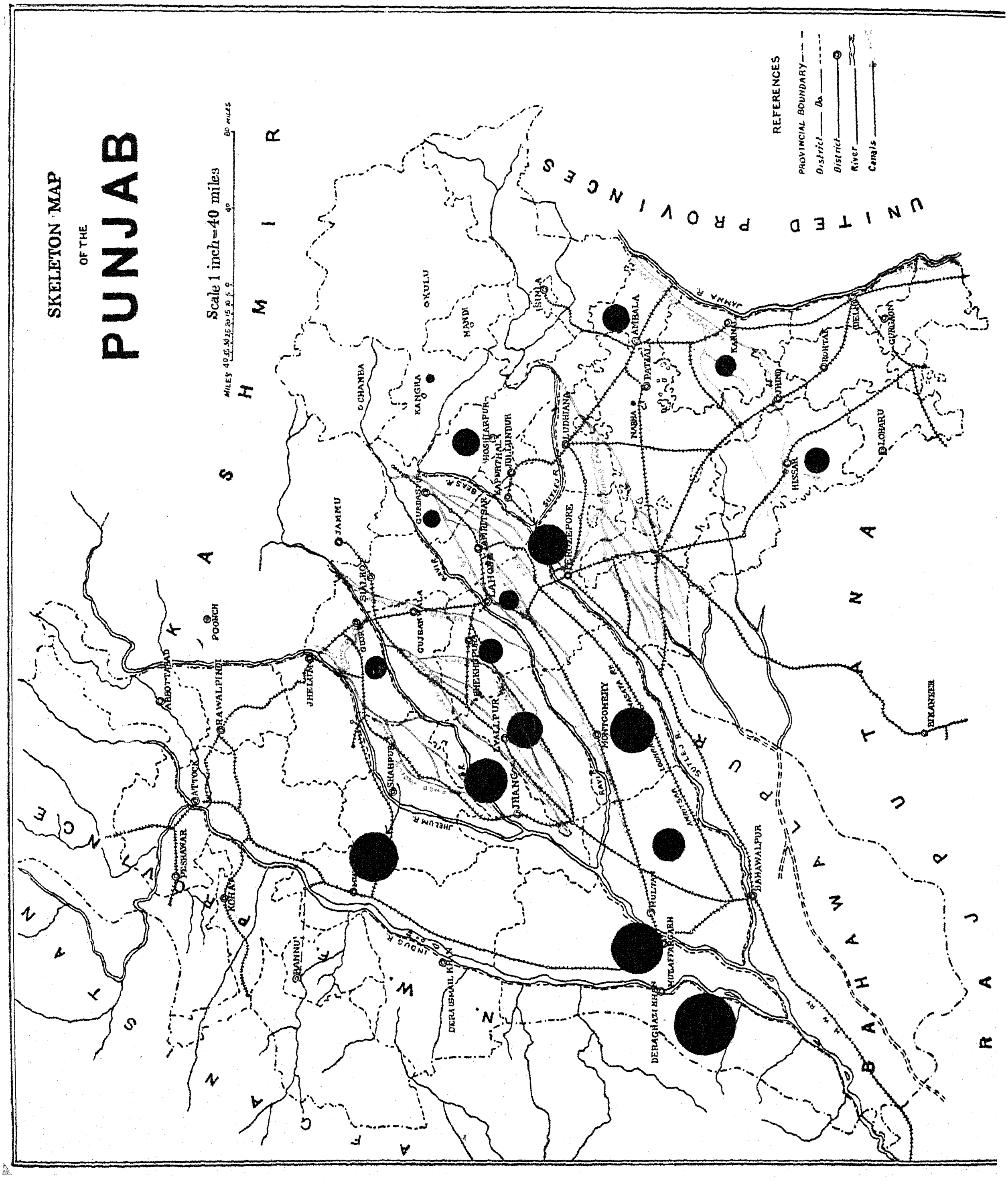
[2] Russel, E. J. Modern applications of Chemistry to crop production, 1922.

[3] Robinson, G. W., and Hill, C. F. Further studies on the soils of North Wales. *Journal Agricultural Science*, Volume IX, 1919.

[4] Robinson, G. W. Variations in the Chemical composition of Soils. *U S. A. Deptt. Agri. Bull.* 551, 1917.

DIAGRAM VIII.

Showing, lime centent of soils from different districts of the Punjab.



exceptions (which may partly be due to errors introduced in certain cases in the determination of this figure), the ratio falls between 0·01 and 0·02, *i.e.*, nitrogen constitutes from 1 to 2 per cent. of the loss which occurs on ignition of the Punjab soils.

3. *Lime.*

The manifold functions of lime in the soil render the question of the lime content very important. It not only keeps the soil in a flocculant condition and helps in the decay and nitrification of organic matter, but also preserves the soil flora against fungoid diseases and exercises considerable influence in the selection of manures. Diagram VIII represents graphically the quantity of lime present in some of the districts of the Punjab. It is based upon the limited number of soil samples so far examined which in some cases are far from sufficient to justify one in striking an average, while in others—though the number is not very small—the soils have been taken from but a limited number of localities in the district and hence are not representative of the whole tract. They are, however, represented in the diagram as indicating a possible method of classification or interpretation, but the diagram will undoubtedly require considerable modification as more data accumulate. The black circle indicates the amount of lime present in soil from a particular district in terms of relative average percentages. It will be seen that with the exception of Ferozepur there appears to be a tendency for the lime content to increase progressively from the Himalayas to the south-west. One may note here that Barnes and Barkat Ali[1] observed that the ferrous iron held in solution in the sub-soil water progressively increased from the surface downwards, and also with the distance from the Himalayas. It is apparent from the diagram that the curve of increasing lime content follows the course taken by the rivers in the Punjab, the soils in the north-west dry area being much richer in lime than the soils in the trans-Gangetic plain or even in the sub-montane tract. The soils from the hilly tracts of the Kangra district show but a very small percentage of lime, and it would be interesting to note if the soils from other hill districts show corresponding features. At present the only other soils from hilly tracts examined are those from Attock, but these, as we have already pointed out, are quite abnormal.[2]

It may be argued that the soils situated in the north-east of the Punjab are deficient in lime. This, however, is an assumption which needs qualification for the following reasons :—

1. The samples examined were all taken from plots which represent good fertile portions of the tract and were giving good yields of crop, which compared favourably with those raised in earlier years.

[1] Barnes and Barkat Ali. Chalybeate waters from tube wells in the Punjab ; their significance to the municipal Engineer and to manufacturer. *Agricultural Jour. of India*, Vol. XII, 1919.

[2] We have also examined some soils from Srinagar-Kashmir, (analysis not given), but Srinagar being situated on a plateau of high altitude, and the locality from which these were taken situated at the foot of a small hill called Mahadev, does not show the characteristics of hill soils. The analyses of these soils therefore, is not comparable with those of the Kangra soils. We hope to take up the study of the hill soils separately.

2. The addition of lime to such soils has not resulted in any increase in the crop yield.

Such soils do not at present show any indication of lime deficiency but it is possible that the quantity of lime present therein may be exhausted much sooner than from soils in regions of high lime content and hence carefully controlled observations are necessary as time goes on.

Investigations are in progress at the present time in the Lyallpur Laboratories to study the relationship between the mineral constituents of the soil and the nutritive value of crops raised therefrom. This work when completed should give some insight into the connection between the lime content of soils and the yield of various crops. As has been found, a great deal of lime is removed by crops from the soil, more especially by fodder crops such as, Lucerne and Alfalfa, and the question of confining these crops to particular areas or of liming soils on which these are grown suggests itself for careful consideration. At present the soil with the lowest lime content may still be sufficiently rich in this mineral to produce satisfactory crops, but future depletions of the soil with consequent deterioration of crops from the point of view of calcium content and general mineral balance deserves careful watch and attention.

It might appear from such information as is at present available that there is some definite relative proportion of the mineral elements necessary for the different soils of the Province, under which conditions the soil functions as a "Normal Soil" for the locality, but if this balance of plant food in the soil is disturbed by removal or addition of food ingredients then it may behave abnormally.

The data at present available, however, render it necessary to present such an opinion with some reserve and a much closer and more detailed study of these soils is essential in order that one may be in a position to diagnose their present condition and take due steps for the upkeep of their fertility. The picture which we have endeavourd to draw shows that the question of the lime content is but one of the many future lines of investigation.

4. *Lime and Magnesia.*

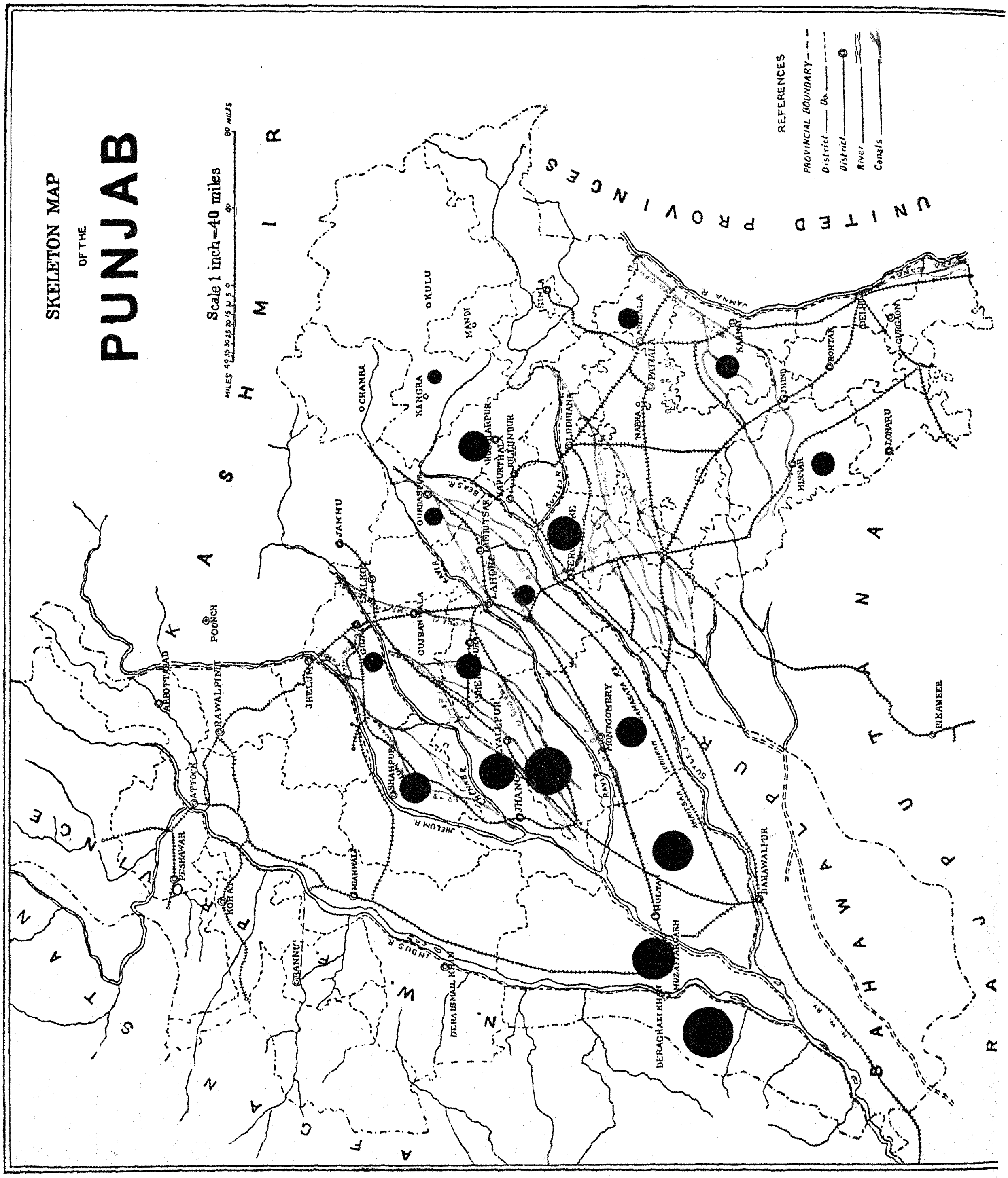
The two metals calcium and magnesium are very closely associated in nature and in conjunction with carbon dioxide they constitute the limestone beds of the world. Magnesium is an indispensable plant food and so is lime. Both are found in the seed of the plant, magnesium even more so than calcium.

Kearney and Cameron in America have shown that salts of magnesium possess, even in solution of great dilution, a toxic affect upon the roots of the plants, which is considerably diminished if calcium salts be also present at the same time. Loew has, at the same time, indicated that a comparative excess of magnesium over calcium in the case of certain soils results in sterility.[1] Thus we see that

[1] Hall, A. D, The Soil. John Murray, Albemere Street London, W., 1921.

DIAGRAM IX.

Showing, lime: Magnesia ratio in soils from different districts of the Punjab.



great importance attaches in soil chemistry to the lime : magnesium ratio. Gila and Ageton (*Jour. Indust. and Eng. Chem.* 1913), have found that certain fertile soils have a ratio as big as 500 : 1. However, in the case of most of the soils the ratio varies between 1 : 1 and 7 : 1.

The quantity of magnesia in the Punjab soils does not vary so greatly as does that of lime. Magnesia is found to an extent of 0·5 per cent. to 3·0 per cent. in the soils we have examined, but most of the figures fall between 1 and 2 per cent. The average figures for the lime-magnesia ratio of the soils tabulated in Tables I and V are depicted in diagram 9, from which it will be clear that the lime-magnesia ratio, with the exception noted above, follows with considerable uniformity the same order as does the lime. For most of the Punjab soils we have examined the ratio varies between 1 : 1 and 6 : 1. We are not yet in possession of sufficient data to enable us to see if any correlation exists between the lime-magnesia ratio and the productiveness of the soils.

5. *Potash.*

Generally speaking the Punjab soils are not deficient in potash. The average quantities found for 150 samples examined is 0·72 per cent., while the sub-soils show an average figure of 0·66 per cent. These figures as well as those for the potash : clay ratio are given in Table VI. From 116 samples for which these ratios are given, a very large number have values of more than 0·35, while only 23 have a ratio of less than 0 35. Thus for most of the Punjab soils potash constitutes $\frac{1}{20}$th to $\frac{1}{10}$th of the clay fraction. The 23 soils referred to above should improve with a dressing of potassic fertiliser, as most of these are heavy soils.

6. *Phosphoric acid.*

The largest amount of phosphoric acid found by Hall and Russell in their survey of the soils of Kent and Sussex was from 0·2 per cent. to 0·25 per cent.[1] Bennet[2] in his study of the soils of the southern states of America found that the maximum content of phosphoric acid in any soils was 0·67 per cent. Most of his soils, however, contain less than 0·05 per cent. Robinson[3] gives 0·09 as the average P_2O_5 content of 35 American surface soils. The highest phosphoric acid content that we have come across in any of the Punjab soils was met with in one sample from Dehra Ghazi Khan, *viz.*, No. 233, with 1·36 per cent. and in another from Shahpur No. 187 which contained 1·60 per cent, these figures, however, are very abnormal. Otherwise most of the Punjab soils have a P_2O_5 content lying between 0·1 to 0·3 per cent., the average of 154 samples working out to 0·18 per cent. The average P_2O_5 content for the subsoils works out at 0·16 per cent. (Table VII.)

[1] Hall, A. D.; and Russell, E. J. Soil Surveys and Soil analysis. *Jour. of Agri. Sci.*, Vol. IV, pp. 182-224.

[2] Bennet, H. H. The Soils and Agriculture of the Southern States. 1921.

[3] Robinson. *Loc. cit.*

7. *Iron and Aluminium.*

Iron and Aluminium have been estimated separately in 71 surface soils and 50 subsoil samples (Table VIII). Most of the surface soils have an iron content lying between 3 per cent. and 5 per cent., while the average for 71 samples is 4·11 per cent. although figures as low as 1·28 per cent. and as high as 5·99 per cent. are also known. Similarly for aluminium most of the figures lie between 4 per cent. and 7 per cent. the average being 5·37 per cent. with a lowest figure of 2·18 per cent. and a highest of 10·19 per cent. The average of the iron aluminium ratio is 0·71, while the lowest ratio met with was found in the Shahpur soils, *viz.*, 0·59 and the highest in those from Amballa, 1·29. The surface soils from Hissar, Karnal, Ferozepur, Sheikhupura and Multan have an iron aluminium ratio about equal to the average figure found. There is a remarkable feature about this ratio. As one moves from the south northwards along the sub-mountain tract, a steady decrease in this ratio is found as shown by the following figures :—

Amballa	1·29
Gurdaspur	·98
Rawalpindi	·75
Attock	·67

and until a considerably larger number of figures is available for these tracts, it is very difficult to say whether any particular significance attaches to them. In the subsoils we find that the figures show a greater uniformity and also are higher than in the surface soils. Most of the samples have an iron content between 3 per cent. and 6 per cent. and an aluminium content between 4 per cent. and 9 per cent., the highest figures being of the same order as for the surface soils.

8. *Aluminium-Clay ratio.*

Table VI gives the figures for the aluminium-clay ratio. Out of 103 samples presented, the majority, *viz.*, 67 have a ratio lying between 0·3 and 0·5 ; 23 have figures less than 0·3, and 13 more than 0·5. Thus for the majority of these soils, alumina constitute one-third to one-half of the clay fraction. The soils from the south of England have figures for alumina which are, generally speaking, one-third of the clay fraction[1].

9 *Silica : Alumina : Bases.*

Ganssen makes the generalisation that the ratio SiO_2 : Al_2O_3 : Bases (CaO, MgO, K_2O, Na_2O) is 3 : 1 : 1, in fertile soils and 3 : 1 : less than 1 in infertile soils. In the English fertile soils the ratio Al_2O_3 : bases is 1 : 1, while in infertile soils it is 1 : less than 1.[2]

We do not possess figures for the amount of alumina and the above bases in the clay fractions of the Punjab soils comparable with the above. However, these

[1] Russell, H. H. Soil condition and plant growth.
[2] Russell, E. J. *Loc. cit.*

ratios for the soil as a whole are given in Table VIII, and, taking the mean averages for different districts we get the following figures :—

—	Residue Al_2O_3	Bases Al_2O_3	Surface Soil	Subsoil
Amballa	30·24	·9	30·24 : 1 : ·9	....
Gurdaspur	21·80	·7	23·38 : 1 : ·7	20·20 : 1 : ·53
Rawalpindi	14·01	2·7	11·77 : 1 : 2·3	16·57 : 1 : 3·19
Hissar	15·64	·7	15·70 : 1 : ·56	12·76 : 1 : ·71
Karnal	15·85	·53	17·57 : 1 : ·58	13·55 : 1 : ·5
Ferozepur	13·06	1·4	13·61 : 1 : 1·4	12·49 : 1 : 1·5
Montgomery	16·41	1·4	16·87 : 1 : 1·45	15·49 : 1 : 1·4
Lyallpur	17·45	1·0	18·76 : 1 : ·95	17·14 : 1 : 1·1
Shahpur	11·63	1·05	11·30 : 1 : ·94	11·55 : 1 : 1·17

It will be seen from the above that this ratio, alumina to bases is 1, or more than 1 for the districts included in the north-west dry area. Ferozepur, which has most of its tract lying on the south-east boundary of this area and has many climatic and physical features in common with this, has got as high a ratio as Montgomery. This means that more inorganic plant food is available in soils from the dry area of the Punjab than in soils from the southern and sub-montane[1] tracts of the Province. Perhaps more heavy rainfall and more intensive cultivation followed in these latter districts is responsible for the more rapid depletion of plant food.

Looking at Table IX we find there is invariably more soluble matter present in the subsoil than in the surface soils. Generally speaking, the bases, calcium, magnesium, sodium and potassium are also present in greater quantity in the subsoils.

8. Some Important crops of the Province.

1. *Wheat.*

Wheat is grown throughout the Province and on all types of land. It possesses considerable power of adaptation and is less localised than, for example, potatoes, rice and fruits. It generally does best on medium loams. Typical examples of wheat soils are given in Table X. These include almost all types of loam, sandy, medium silt and clay soils.

[1] The figures for Rawalpindi are abnormal owing to high amount of calcium present.

2. *Cotton.*

Cotton does quite well on all soils suitable for wheat except that it (more particularly American cotton) requires a comparatively richer soil with a greater and more certain supply of water. It is less hardy as compared with wheat. The analyses of typical cotton soils of the Province are represented in Table XI.

3. *Sugarcane.*

The analyses of those soils of the Province which have proved suitable for sugarcane are given in Table XII. It will be seen that sugarcane requires a somewhat heavier soil than wheat or cotton. It has also been observed that a moderate percentage of gravel in a soil does not detract from its value for cane production. Cane is the only crop which has shown any indication of a "possibly" successful yield in the abnormal *bara* soils of the Montgomery district.

Soils 16 and 19 in the same Table are somewhat too light for the best production of sugarcane, but as they happen to lie in the sub-montaneous tracts they receive a fairly heavy rainfall which counteracts to some degree the lightness of the soils and renders them moderately suitable for cane. This explanation, however, does not hold good for soil No. 103 from Hissar. This soil, though a sandy loam, has the whole of its sand present as fine sand, which confers on it properties similar to those of silt soils.

4. *Rice.*

Some typical rice soils of the Province are shown in Table XIII. It will be seen that rice grows successfully only in heavy soils.

From the table it will be clear that all the samples analysed contain either a fairly high percentage of clay or they are rich in silt and fine silt ingredients which tend to make a soil heavy. All these soils are very rich in iron and aluminium as compared with the wheat, the cotton, and the sugarcane soils.

The soils suitable for different crops are represented in Diagrams 3—6, according to their mechanical analysis.

9. Subsoils.

The analyses of about 50 samples of subsoils are presented in this paper. The surface soil includes the soil layer sampled down to a depth of one foot and the subsoil represents the layers lying below this as far as the third foot. The results of analyses of these subsoils, together with those of the corresponding surface soils, are given in Table I (*a*). The mechanical composition of most of these subsoils and surface soils is represented graphically in Diagram 7. It is clear from the diagram, that with two or three exceptions, the subsoil—although it has a distinct tendency to be heavier than the surface soil—is not widely separated on the scale from the surface soil; as a matter of fact in the large majority of cases, the

soil and the corresponding subsoil fall in one and the same compartment on the graph ; thus showing that they belong to the same soil type.[1]

From a consideration of the relative figures for the more important chemical constituents (Table I*a*), we find that there is no appreciable difference in the amount of potash and phosphates present in the surface soil and subsoil below. Calcium, on the other hand, is in some cases present in greater amount in the surface soils and in some cases in the subsoils. The differences in the amount of nitrogen and organic matter, although not very wide, point to some striking conclusions. As a general rule, in the majority of cases, the amount of nitrogen is greater in the surface soil than in the subsoil, while, on the other hand, the organic matter is less in the surface soil. The greater amount of nitrogen in the surface soils may be due to the greater acitivity of the nitrogen fixing organisms in the upper layers. However, more extensive examination of the soils is necessary before any generalisation is possible.

Such small differences referred to above, however, do not cause any serious modification in the character of the subsoil. It may be safely asserted that, as a general rule, throughout the Punjab the subsoil does not differ very materially from the surface soil either in its chemical or mechanical composition, and owing to this uniformity the properties of the surface soil instead of being in any way modified are merely intensified.

10. The Barren lands of the Province.

(*a*) ALKALI SOILS.

Although much of the barren land of the Punjab owes its non-fertility to its excessively sandy nature, as in various parts of the Thal, or in some of the barani tracts of the Central Punjab, yet taken on the whole their sterility is caused by the presence of excessive quantities of alkali salts.

Most of these *kallar* lands contain only white alkali such as chlorides and sulphates of sodium, but the occurrence of black alkali is not uncommon. No records are available from which we may accurately compute the exact amount of *kallar* land in the Province, but rough estimates show that smething like 4,000 square miles of *kallar* exist throughout the Punjab.[2] With the increasing development of the Punjab canal system, the problems connected with *kallar* and waterlogging are yearly increasing and becoming more accute. Generally speaking, these alkali salts are present in harmful degree only in the first few inches of the surface soils, but sometimes the subsoil layers are also found to be impregnated with salt, in which case problems of reclamation become increasingly difficult. The analyses of the water extracts of the alkali soils from various parts of the Province

[1] Wilsdon, B. H. *Loc. cit.*

[2] Mehta, M. L. Occurrence of Saline lands in the Punjab. *Proceedings of the 4th annual gathering of the Old Boys Association of the Punjab Agricultural College, Lyallpur*, India, 1924.

are given in Table XIV and when a total water soluble figure above 0·8 per cent. is found it may be assumed that we are dealing with a *kallar* soil.

The chief sources of origin of alkalis in the Punjab are attributable to :—

1. Movement of subsoil water currents from high water levels to lower ones and the accumulation of salt on account of the evaporation of water from the land to which it has drained.
2. Contamination from salt mines.
3. Seepage from canals, the result of which is waterlogging and as a result of free evaporation an accumulation of salt on the surface.
4. The constructions of canals. Sometimes the surface drainage of the country is disturbed owing to this cause, the result being an accumulation of salt in the soil.
5. The formation of vast sheets of stagnant water or huge lakes.
6. Bad aeration and drainage.

The last, according to Howard, results in the production of hydrogen sulphide and metallic sulphides through the agency of anerobic bacteria. These products, upon cultivation, *i.e.*, improvement in aeration and drainage, are oxidised to harmful alkali salts which rise to the surface.

The only methods which have so far been tried with any degree of success in order to reclaim alkali lands are, firstly the scraping of salts from the surface and secondly the construction of mole drains and subsequent flooding to wash the salt to lower subsoil strata. At the present time the effect of calcium in destroying the "Soda Complex," *i.e.*, sodium silicates which renders the land hard and impermeable to water, is being studied, but the work is still in an experimental stage.

(*b*) *Bara*.

Bara soil is an alkali soil which presents certain very peculiar and distinguishing features. It is extremely arid, dense in texture, and most intractable. It is highly charged with salts and usually cracks into hexagonal shaped clods which on drying form a thin and peculiar crust which can be peeled off. Water, when applied to the surface of *Bara* soil, hardly percolates at all, but merely evaporates, leaving a surface of extraordinary hardness which produces a metallic sound when a horse rides over it and exhibits very clearly the phenomena of mirage when seen from a distance. The surface layer (*papri*) usually contains as much as 80 per cent. clay (Table below), and is very impervious to water.

Mechanical analysis of Papri

Fine gravel	*nil.*
Coarse sand	*nil.*
Fine sand	*nil.*
Silt	3·28 per cent.
Fine silt	13·00 per cent.
Clay	78·40 per cent.

This material, although containing such a high percentage of clay is not at all sticky when wet, and if kept under water for an hour or so, does not pass into suspension; on the other hand, it is possible to separate this clay into layers of several fine leaves. If this *papri* is treated with water and kept for a couple of days it develops a very offensive smell, but not so in the presence of mercury chloride. Shells of various sizes and description have been found in the *bara* soils from which fact it may be concluded that the soil was most probably deposited under water, the water gradually evaporating and leaving behind deposits of soluble salt. An analysis of typical *bara* and normal lands in the Montgomery district is given in Tables XV and XVI.

(c) Bari.

This is a lighter type of *bara*.

It has been estimated that in the Montgomery Colony alone there exists something like 3 lakhs of acres of *bara* and *bari* types of land, and on enquiry it was found that another 163,186 acres of similar land are found in the adjoining districts.

The problem of the reclamation of *bara* has presented many difficulties. An experimental station near Harrappa Road Railway station (N. W. R.) was started some 9 years ago for the study and investigation of the most economical methods of reclaiming these lands. An economic method of reclaiming *bara* land has not yet been found, but work is still progressing and so far the application of gypsum followed by flooding and the planting of trees have given the best results.[1] There is no doubt that the land can be reclaimed provided sufficient time and money are forthcoming.

It has been noticed that *bara* land shows a tendency to pass into ordinary *kallar* both with and without any treatment with water. One square of land on the experimental farm was under flooding experiments in 1925, when it was kept under 6 inches of water for about 3 months. In 1926 only a part of this land was under water, the rest was either sown with *chari* and *moth* or kept fallow. All that portion, not actually under water, developed *kallar* on its surface, scrapings from which on analysis gave the following figures :—

	per cent.
Total saline matter	8·15
Carbonates	0·02
Bicarbonates	0·03
Chlorides	2·26
Sulphates	5·27

This shows that the land has developed a very bad type of white alkali.

[1] Nasir, S. M. Some observations on the Barren Soils of Lower Bari Doab Colony in the Punjab. *Agri. Research Institute, Pusa, Bull.* 145, 1923.

11. Some Virgin lands.

In the year 1920, a preliminary reconnaissance of the crown lands covered by the Sutlej valley project (Nili Bar) was undertaken, mainly with the object of making a preliminary study for a more detailed and scientific survey of these lands later on, schemes for which were under the consideration of Government.

During the course of this inspection, a few samples of soils were taken from some of the typical tracts of the Bar and their analyses are given in Table XVII. It is not proposed to describe in any detail the effect of development on them or to discuss the best method of handling them when first colonised, but the analyses are presented in the hope that they will be useful for future reference. Soil No. I was taken from an uncultivated field of land commanded by a well (Faqirwala) near the town of Kabullah. The lands near by bear fairly good crops under well irrigation.

Soil No. 2 was taken from a tract situated on the road between Kabullah and Tibi Lal Beg and was covered by a forest of Karil (*Capperis-aphylia*), Van (*Salva-Dora Olsides*) and Jand (*Presopis Spicigera*) trees. It grows a very good crop of grass and was being used for grazing cattle. The land is rather hard on the surface, but the subsoil layers are decidedly sandy.

Soil No. III is from a similar tract on the same road.

Soil No. IV. This was taken from lands situated in the village Sadullahpur which lies between Jamlera and Kabullah. The soil is very good and is expected to yield good crops when brought under cultivation.

Soil No. 5. This sample was taken from a plot at Jamlera. It is at present commanded only by flood water from the river Sutlej. The land was covered by a very thick forest of Jand (*Prosopis Spicigera*) trees and provided the best type of soil found.

Soil No. 6. This is of the same type as No. 5 although not considered to be as good. It was taken from land commanded by the Matewala well, but was neither irrigated nor cultivated.

Soil No. 7. This was taken from a place named Bisakhiwala from the portion of the Nili Bar situated in the Multan district.

Table No. XVI shows some analyses of good soils of the Montgomery colony before they were first broken up for cultivation.

From the foregoing it is clear that a considerable diversity of soil types exists in the Province. Taking into consideration the variety of climatic conditions prevailing in the different parts of the Punjab, it seems obvious that a more detailed study of the soils of the Province is a necessity in order to elaborate successfully a more exact system of crop and animal husbandry. For this purpose a regular soil survey is necessary. A soil survey is essentially an inventory of the soils of the State, and corresponds to the work of the geological survey which investigates the mineral resources, such as coal, iron, oil, etc., in order to discover new deposits and determine the extent of those already present. It is essentially

important that Government should undertake soil investigations of this kind so that the soil, the primary source of wealth, may be utilised to yield to its maximum capacity, and conserved in good condition to subserve the needs of future generations. As agriculture is the chief and the only permanent basis of the wealth of the Province, the necessity of comprehensive studies in this field is obvious.

The work of the Bureau of soils of the United States Department of Agriculture may be quoted as an example of activities in this direction.[1] More than 1,220,000 sq. miles, or over 40 per cent. of the total area of the United States, has now been surveyed, and the surveys are progressing at the rate of about 30,000 sq. miles per year. The usefulness of the undertaking has been very much increased by supplementing the general survey in various ways, notably with more detailed studies of the various soil types, their fertility needs and adaptability to diffierent crops.

As a result of these exhaustive surveys, many experimental stations have been established each of which is engaged on specific soil problems specially related to the area in which the station is situated.

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[1] Reports of the third annual meeting of the American Association of Soil Survey Workers, Vols I—VI, 1922-26.

12. Appendix A.

METHOD FOR THE MECHANICAL ANALYSIS OF SOILS.

At Lyallpur a centrifugal method of separating clay has been introduced and has been found to give satisfactory results with considerable economy of time.

The method followed is the same as that given by Auld and Ker[1] with the modification that samples are prepared in a specially constructed shaking machine and that clay is separated by spinning out muddy liquids in a centrifugal machine specially made for this purpose.

Appendix B.

THE MECHANICAL ANALYSIS OF SOILS.

1. *Water extract.*

200 grams of the air dried fine earth are taken up in Winchester bottle in 2,000 c.c. of distilled water. The bottle is shaken after every 15 minutes and allowed to stand overnight. The muddy liquid is then filtered through a Berkefeld filter pump.

50 to 100 c.c. of the water extract is evaporated to dryness in a platinum dish and weighed; the difference in weight after allowing for the loss of carbon dioxide and water gives the amount of total solids.

Chlorides, carbonates and bicarbonates are estimated by the usual volumetric methods, while sulphates are estimated gravemetrically.

2. *Citric acid extract.*

200 grams of air dried soil are placed in a Winchester bottle with two litres of 1 per cent. citric acid. The bottle is occasionally shaken and the soil allowed to remain in contact with acid for a week, after which the extract is decanted and analysed.

3. *Hydrochloric acid extract.*

20 grams of air dried fine soil are treated with 60 c.c. of strong hydrochloric acid in a conical flask. The flask is put on the sand bath and the contents heated for 8 hours at such a temperature as to cause occasional ebullition. After this the extract is filtered and made up to 500 c.c.s.; aliquots of the filtered extract are then taken for the estimations.

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[1] Auld and Ker. Practical Agricultural Chemistry.

4. *Organic nitrogen.*

The Gunning method, involving the use of one gram of $Cuso_4$ $5H_2O$ with subsequent addition of 10 grams of K_2So_4, is in use at Lyallpur. The quantity of soil used is 20 grams.

5. *Total nitrogen.*

The nitrates are reduced by digesting the soil with 6 per cent. salicyl sulphuric acid.

TABLE I.

Analyses of the Punjab Soils.

LOCALITY	KANGRA							AMBALLA	
DESCRIPTION	Dharamsala		Holta	Nur Nassam	Nassam	BAIJ NATH			
						Lower garden	Upper garden		
Number	1	2	3	4	5	6	7	8	9
Mechanical.									
Fine gravel	23·2	9·27	0·91	0·76	0·88	0·39	0·60	*nil*	*nil*
Coarse sand	40·0	26·18	1·12	2·81	0·69	2·47	33·30	0·89	0·34
Fine sand	16·18	17·93	7·06	6·87	8·17	8·17	18·87	71·79	13·49
Silt	7·30	13·18	23·60	20·60	24·90	32·41	12·51	13·07	30·68
Fine silt	6·88	15·95	21·74	20·46	23·40	25·20	18·40	7·36	32·80
Clay	5·8	12·10	33·60	35·05	36·21	19·00	11·72	4·80	19·60
Chemical. (H Cl extract)									
Potash as K_2O	0·714	0·687	0·728	0·683	0·713	0·423	0·414	0·411	0·974
Phosphoric acid as P_2O_5	0·340	0·790	0·390	0·470	0·340	0·296	0·224	0·160	0·213
Lime as CaO	0·058	0·035	0·092	0·081	0·127	0·260	0·090	1·190	0·850
Magnesia as MgO	0·290	0·360	0·660	0·280	0·780	0·304	0·110	0·851	1·359
Iron and Aluminium (Fe_2O_3) Al_2O_3	10·890	10·750	21·80	22·22	19·55	11·61	14·41	6·910	13·552
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·050	0·150	0·076	0·050	0·110	0·110	0·100	0·020	0·054

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	AMBALLA					HOSHIARPUR		GURDASPUR	
DESCRIPTION									
Number	10	11	12	13	14	15	16	17	18
Mechanical.									
Fine gravel	*nil*	*nil*	*nil*	0·048	0·044	0·68	0·03	*nil*	*nil*
Coarse sand	2·96	19·135	14·10	25·92	9·18	21·02	36·60	14·88	6·08
Fine sand	50·82	43·27	34·33	47·84	51·12	41·46	38·54	31·84	15·84
Silt	24·63	15·28	17·07	10·53	17·72	14·40	10·88	23·47	28·05
Fine silt	11·36	10·96	19·68	8·96	11·76	10·88	6·4	23·25	40·39
Clay	6·72	6·08	9·92	7·44	10·56	8·32	7·04	4·09	4·62
Chemical.									
Potash as K_2O	0·22	0·27	0·29	0·46	0·48	0·599	0·418	0·688	0·638
Phosphoric acid as P_2O_5	0·139	0·107	0·242	0·184	0·145	0·458	0·133	0·163	0·178
Lime as CaO	0·93	1·04	0·72	1·05	1·09	2·510	·625	0·485	0·520
Magnesia as MgO	1·15	1·05	1·19	0·91	1·06	1·100	·849	2·250	1·950
Iron and Aluminium (Fe_2O_3) Al_2O_3	3·21+ 2·53	3·29+ 2·44	3·68+ 3·07	2·34+ 3·57	2·95+ 3·73	6·712 ..	5·842 ..	11·922 ..	9·807 ..
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·061	0·039	0·053	0·039	0·041	0·052	0·055	0·075	0·058

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	GURDASPUR								
DESCRIPTION									
Number	19	20	21	22	23	24	25	26	27
Mechanical.									
Fine gravel	*nil*	0·71	0·14	0·24	0·16	0·11	0·24	0·16	0·29
Coarse sand	35·99	7·46	23·09	38·29	40·93	28·07	32·94	36·56	40·84
Fine sand	30·22	31·64	33·11	19·92	21·52	28·21	24·30	24·47	19·75
Silt	11·52	23·40	19·85	17·24	16·85	20·47	20·08	17·98	16·36
Fine silt	10·24	20·48	12·16	13·60	12·24	13·36	13·04	12·56	14·96
Clay	9·28	11·20	9·12	6·40	5·92	6·40	6·40	6·32	7·36
Chemical.									
Potash as K_2O	0·744	0·831	0·688	0·366	0·343	0·381	0·448	0·422	0·443
Phosphoric acid as P_2O_5	0·113	0·105	0·055	0·710	0·650	0·560	0·640	0·620	0·820
Lime as CaO	0·370	0·835	0·390	0·350	0·300	0·510	0·300	0·480	0·430
Magnesia as MgO	1·400	1·630	1·050	0·460	0·980	1·170	0·880	1·170	1·230
Iron and Aluminium (Fe_2O_3) Al_2O_3	8·707	10·695	7·325	7·820	7·400	7·490	7·620	7·050	7·230
Potash (available)	..	..	..	0·015	0·014	0·013	0·015	0·014	0·017
Phosphoric (available)	..	..	..	0·023	0·032	0·025	0·026	0·020	0·025
NITROGEN (% on air dried soil)	0·033	0·047	0·032	0·048	0·045	0·046	0·049	0·046	0·048

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	GURDASPUR								
DESCRIPTION									
Number	28	29	30	31	32	33	34	35	36
Mechanical.									
Fine gravel	1·14	0·25	0·41	0·48	0·23	0·11	..	..	..
Coarse sand	25·96	23·00	23·87	8·13	14·30	23·70	..	..	..
Fine sand	28·10	22·91	31·30	19·02	25·84	27·23	..	..	..
Silt	16·10	20·01	17·92	27·45	26·82	25·44	..	..	..
Fine silt	12·71	17·93	12·99	26·02	18·20	12·94	..	..	..
Clay	10·23	15·60	12·48	12·96	9·28	7·36	..	..	..
Chemical.									
Potash as K_2O	0·351	0·304	0·292	0·314	0·336	0·317	0·910	1·250	1·030
Phosphoric acid as P_2O_5	0·449	0·435	0·486	0·409	0·438	0·330	0·120	0·160	0·140
Lime as CaO	0·900	0·280	0·270	0·290	0·294	0·271	..	..	..
Magnesia as MgO	1·030	0·970	0·820	0·620	1·040	0·790	..	..	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	8·080	9·010	6·870	10·840	8·470	8·070	..	..	..
Potash (available)	0·050	0·032	0·027	0·023	0·023	0·022	0·012	0·016	0·017
Phosphoric (available)	0·147	0·082	0·112	0·035	0·066	0·038	0·009	0·033	0·013
NITROGEN (% on air dried soil)	0·063	0·058	0·052	0·078	0·075	0·052	0·059	0·078	0·048

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	GURDASPUR								
DESCRIPTION									
Number	37	38	39	40	41	42	43	44	45
Mechanical.									
Fine gravel	..	..	..	..	..	..	..	..	..
Coarse sand	..	..	..	..	..	..	..	..	..
Fine sand	..	..	..	..	..	..	..	..	..
Silt	..	..	..	..	..	..	..	..	..
Fine silt	..	..	..	..	..	..	..	..	..
Clay	..	..	..	..	..	..	..	..	..
Chemical.									
Potash as K_2O	0·940	1·700	1·380	0·880	0·720	0·870	0·910	0·990	1·220
Phosphoric acid as P_2O_5	0·070	0·180	0·100	0·050	0·060	0·060	0·065	0·180	0·070
Lime as CaO	..	..	..	..	..	..	..	..	..
Magnesia as MgO	..	..	..	..	..	..	..	..	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	..	..	..	..	..	..	..	..
Potash (available)	0·014	0·015	0·022	0·010	0·061	0·050	0·025	0·011	0·014
Phosphoric (available)	0·011	0·013	0·011	0·011	0·008	0·026	0·025	0·019	0·011
NITROGEN (% on air dried soil)	0·057	0·085	0·070	0·050	0·056	0·055	0·063	0·050	0·062

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	GURDASPUR							
DESCRIPTION			1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.
Number	46	47	48	49	50	51	52	53
Mechanical.								
Fine gravel	..	*Nil*	*nil*	·40	*nil*	*nil*	*nil*	*nil*
Coarse sand	..	30·01	23·41	23·83	12·44	*nil*	11·04	15·33
Fine sand	..	32·27	21·39	18·94	51·59	36·79	31·57	29·19
Silt	..	16·70	18·90	17·60	23·61	20·68	35·14	31·82
Fine silt	..	12·72	19·57	20·65	8·92	14·32	13·34	14·99
Clay	..	6·24	14·80	21·36	6·84	19·04	7·28	11·70
Chemical.								
Potash as K_2O	1·260	..	0·52	0·57	0·43	0·53	0·48	0·44
Phosphoric acid as P_2O_5	0·050	..	0·10	0·11	0·08	0·06	0·16	0·14
Lime as CaO	..	..	0·56	0·28	0·84	0·85	0·41	0·39
Magnesia as MgO	..	..	1·26	1·36	1·20	1·53	1·77	0·83
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	..	4·24 4·68	4·60 5·33	3·16 3·47	3·52 4·35	3·08 3·56	3·38 3·77
Potash (available)	0·012	..	..	..	..	..	..	..
Phosphoric (available)	0·016	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·053	..	0·059	0·066	0·075	0·043	0·033	·066

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	RAWALPINDI						ATTOCK		
							VILLAGE SADKAL		
DESCRIPTION	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.	3rd ft.
Number	54	55	56	57	58	59	60	61	62
Mechanical.									
Fine gravel	0·53	0·22	0·14	0·02	0·21	0·06	0·63	..	0·42
Coarse sand	2·37	1·26	1·02	·70	35·70	31·58	1·50	1·60	1·40
Fine sand	26·86	25·58	19·38	19·82	29·70	28·86	28·52	26·38	13·58
Silt	32·15	34·50	25·96	27·20	16·18	16·41	28·13	27·41	31·56
Fine silt	17·92	17·36	24·80	24·24	6·16	9·60	18·80	22·96	26·40
Clay	13·92	14·08	22·08	22·24	8·64	6·72	21·56	23·00	27·25
Chemical.									
Potash as K_2O	0·700	0·586	0·496	0·514	0·302	0·469	0·765	0·882	0·727
Phosphoric acid as P_2O_5	0·198	0·175	0·214	0·208	0·160	0·172	0·170	0·190	0·176
Lime as CaO	11·44	10·13	11·20	11·39	9·07	9·55	1·95	1·99	1·97
Magnesia as MgO	1·75	1·76	2·17	2·39	1·19	1·28	1·27	1·21	0·97
Iron and Aluminium (Fe_2O_3)	5·09	4·93	3·66	3·40	4·52	4·48	4·32	4·50	4·31
Al_2O_3	5·95	5·38	5·91	3·48	5·86	3·92	7·13	8·86	6·11
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·067	0·086	0·041	0·048	0·059	0·046	0·053	0·050	0·045

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	ATTOCK								
	VILLAGE AJJUWALA			VILLAGE KHARALA KHURD			VILLAGE JHANG (IRRI).		
DESCRIPTION	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.
Number	63	64	65	66	67	68	69	70	71
Mechanical.									
Fine gravel	0·88	0·98	0·62	0·93	0·93	1·23	0·73	0·81	1·18
Coarse sand	5·40	4·58	3·20	4·20	4·20	6·01	1·97	1·61	1·40
Fine sand	25·88	23·02	8·88	31·70	32·68	27·38	18·40	18·31	18·01
Silt	12·62	8·84	9·44	23·94	25·66	22·55	30·27	31·96	27·18
Fine silt	27·44	29·60	40·00	22·00	21·44	22·80	30·00	29·76	32·40
Clay	27·28	32·40	39·52	21·62	20·98	19·35	20·58	21·12	20·56
Chemical.									
Potash as K_2O	0·552	0·46	0·780	0·424	0·407	0·395	0·202	0·616	0·597
Phosphoric acid as P_2O_5	0·100	0·149	0·105	0·165	0·090	0·101	0·157	0·104	0·095
Lime as CaO	12·81	12·88	12·88	7·71	8·37	7·90	8·89	2·35	5·95
Magnesia as MgO	1·57	1·68	1·59	2·29	2·30	2·46	1·99	2·23	1·92
Iron and Aluminium (Fe_2O_3) Al_2O_3	4·21 6·31	4·30 5·84	4·22 7·89	4·93 6·78	4·32 5·68	5·60 6·64	5·99 7·73	6·00 9·37	5·48 7·67
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·071	0·055	0·054	0·037	0·037	0·043	0·093	0·054	0·043

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	ATTOCK								
DESCRIPTION	VILLAGE JHANG BARANI			VILLAGE NEKA (IRRI.)			VILLAGE NEKA BARANI		
	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.
Number	72	73	74	75	76	77	78	79	80
Mechanical.									
Fine gravel	1·48	1·05	1·76	2·26	1·42	1·46	1·52	1·56	0·88
Coarse sand	3·20	2·00	1·54	7·40	4·50	3·18	5·44	5·50	5·58
Fine sand	39·29	22·09	17·32	20·42	25·63	21·08	33·54	31·06	26·56
Silt	22·39	30·48	28·78	24·08	23·08	26·64	26·00	24·24	27·51
Fine silt	17·76	27·36	30·40	22·68	21·86	24·40	16·32	20·00	17·20
Clay	14·28	17·63	22·36	21·44	25·80	25·20	16·80	19·20	17·62
Chemical.									
Potash as K_2O	0·524	0·543	0·638	0·677	0·716	0·519	0·632	0·491	0·485
Phosphoric acid as P_2O_5	0·104	0·091	0·129	0·365	0·280	0·271	0·260	0·162	0·192
Lime as CaO	5·89	4·51	3·95	9·14	8·85	8·74	8·20	10·92	10·92
Magnesia as MgO	1·65	1·45	1·80	2·20	0·95	1·02	1·08	1·49	1·00
Iron and Aluminium (Fe_2O_3) Al_2O_3	4·72 6·01	5·20 7·83	6·08 7·67	4·08 5·67	3·36 8·96	3·41 7·69	3·58 9·29	3·20 9·42	3·69 7·06
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·047	0·049	0·077	0·090	0·062	0·062	0·069	0·067	0·065

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	ATTOCK								
DESCRIPTION	VILLAGE KUTBAL			VILLAGE DOIAN			VILLAGE KHUNDA		
	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.
Number	81	82	83	84	85	86	87	88	89
Mechanical.									
Fine gravel	2·76	0·96	2·92	5·04	5·74	1·34	0·62	0·59	0·76
Coarse sand	5·97	5·86	7·57	4·50	8·44	4·78	24·95	21·64	21·00
Fine sand	17·48	24·48	20·64	27·17	22·58	22·60	20·96	22·38	23·08
Silt	28·48	24·40	25·70	24·64	23·84	28·30	12·38	17·19	15·97
Fine silt	24·00	26·00	25·44	19·60	22·40	22·40	26·40	20·50	20·24
Clay	19·20	19·04	16·96	20·28	17·86	19·20	14·50	16·00	15·00
Chemical.									
Potash as K_2O	0·517	0·798	0·650	0·872	0·836	1·062	0·764	0·810	0·750
Phosphoric acid as P_2O_5	0·200	0·095	0·116	0·124	0·078	0·044	0·036	0·040	0·038
Lime as CaO	12·18	11·31	12·04	13·20	16·60	9·83	5·10	6·16	16·05
Magnesia as MgO	1·29	2·04	1·86	1·56	1·47	1·82	1·42	1·52	1·42
Iron and Aluminium (Fe_2O_3) Al_2O_3	5·58 7·31	5·20 7·06	5·36 7·22	4·86 6·98	4·92 7·16	5·40 7·88	4·96 7·86	5·71 8·65	5·88 8·52
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·066	0·064	0·063	0·056	0·042	0·051	0·087	0·046	0·078

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	HISSAR								
DESCRIPTION	1st ft. Black soil							1st ft.	2nd ft.
Number	90	91	92	93	94	95	96	97	98
Mechanical.									
Fine gravel	0·76	*nil*	*nil*	0·43	0·08	0·12	0·26	*nil*	*nil*
Coarse sand	16·96	·41	1·30	0·60	0·46	4·46	0·12	2·51	2·42
Fine sand	20·18	60·28	65·55	62·38	66·08	59·12	36·40	60·41	59·00
Silt	16·74	9·89	9·29	10·11	11·39	11·59	9·75	11·35	10·24
Fine silt	25·60	9·44	9·12	9·28	11·20	8·32	14·88	7·68	9·12
Clay	19·20	15·52	13·44	12·80	14·72	11·20	33·44	16·48	21·76
Chemical.									
Potash as K_2O	0·761	1·680	0·495	0·640	0·717	0·710	1·279	0·682	0·627
Phosphoric acid as P_2O_5	0·073	0·155	0·113	0·160	0·138	0·140	0·118	0·316	0·316
Lime as CaO	3·44	·825	·985	2·040	·920	1·045	·890	2·02	2·36
Magnesia as MgO	2·10	1·648	·863	1·070	·865	1·370	·619	1·34	1·39
Iron and Aluminium (Fe_2O_3) Al_2O_3	5·94 8·80	8·335	8·112	8·415	8·752	8·725	15·642	3·28 4·58	3·56 5·96
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·052	0·053	0·039	0·042	0·053	0·039	0·049	0·074	0·042

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	HISSAR									
DESCRIPTION	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.				
Number	99	100	101	102	103	104	105	106	107	108
Mechanical.										
Fine gravel	0·04	*nil*	*nil*	*nil*	0·07	0·04	0·45	0·22	0·20	*nil*
Coarse sand	7·85	9·16	1·48	0·86	0·62	0·50	2·24	2·02	0·33	0·52
Fine sand	47·05	42·84	33·91	27·87	60·77	53·85	47·25	53·50	49·47	58·14
Silt	14·38	13·29	17·24	15·87	16·85	20·51	19·40	16·20	15·98	14·40
Fine silt	13·76	14·08	19·36	20·32	9·28	10·24	15·85	14·45	19·88	11·68
Clay	18·40	21·28	26·08	36·64	14·24	15·52	15·30	13·28	15·84	15·66
Chemical.										
Potash as K_2O	0·666	0·591	0·736	0·771	0·570	0·382	0·91	1·01	0·94	0·64
Phosphoric acid as P_2O_5	0·236	0·226	0·185	0·166	0·218	0·205	0·149	0·319	0·148	0·149
Lime as CaO	2·65	2·61	1·37	1·12	1·16	1·31	1·11	1·23	1·11	0·78
Magnesia as MgO	1·17	1·62	1·49	1·27	0·53	0·63	0·69	0·69	0·75	0·66
Iron and Aluminium (Fe_2O_3) Al_2O_3	4·10 6·74	4·20 6·10	4·96 6·99	5·12 8·00	7·48 1·36	5·60 3·29	4·04 4·71	3·84 5·88	4·08 5·50	3·80 5·59
Potash (available)	..	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil).	0·081	0·054	0·063	0·048	0·038	0·043	0·048	0·054	0·050	0·042

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	HISSAR	KARNAL							
DESCRIPTION									
Number	109	110	111	112	113	114	115	116	117
Mechanical.									
Fine gravel	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*
Coarse sand	0·40	9·84	2·38	1·84	9·15	9·96	29·32	2·83	·49
Fine sand	58·35	40·32	46·05	26·50	66·00	15·90	62·30	40·90	32·30
Silt	13·22	15·38	18·17	32·30	14·10	38·95	3·10	29·38	34·10
Fine silt	12·88	17·92	18·24	34·32	5·08	26·04	1·12	13·76	18·84
Clay	16·60	14·72	16·16	8·68	1·48	10·60	1·36	6·48	8·56
Chemical.									
Potash as K_2O	0·79	0·873	0·883	..	..	..	..	..	..
Phosphoric acid as P_2O_5	0·128	0·363	0·385	..	..	..	..	..	..
Lime as CaO	0·62	2·170	1·275	..	..	..	..	..	..
Magnesia as MgO	0·61	1·292	1·549	..	..	..	..	..	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	3·68 4·85	8·742	8·820	..	..	..	..	..	..
Potash (available)	..	..	..	·031	·026	·027	·025	·037	·047
Phosphoric (available)	..	..	..	·012	·007	·013	·009	·006	·009
NITROGEN (% on air dried soil)	0·030	0·051	0·047	0·066	0·024	0·074	0·011	0·080	0·074

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	KARNAL								FEROZE-PUR
DESCRIPTION		1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.		
Number	118	119	120	121	122	123	124	125	126
Mechanical.									
Fine gravel	*nil*	·21	·08	·05	·17	·06	·14	*nil*	*nil*
Coarse sand	2·06	1·68	1·10	1·74	1·41	1·09	1·13	21·0	7·90
Fine sand	13·80	46·73	40·74	47·29	42·64	42·45	44·37	36·62	26·84
Silt	26·86	20·91	19·96	18·67	17·13	22·98	18·81	25·18	26·67
Fine silt	30·82	16·16	16·96	13·92	16·56	15·76	16·00	10·86	17·75
Clay	19·12	9·44	16·64	16·96	12·96	9·44	14·88	7·52	14·56
Chemical.									
Potash as K_2O	..	0·65	0·65	0·67	0·91	1·10	0·88	0·64	1·090
Phosphoric acid as P_2O_5	..	0·13	0·10	0·12	0·14	0·14	0·13	0·13	0·235
Lime as CaO	..	0·58	0·44	0·43	0·78	0·84	0·63	1·09	4·130
Magnesia as MgO	..	1·43	1·43	1·34	1·28	1·38	1·45	0·46	2·645
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	4·08 4·86	4·20 4·75	4·08 5·02	3·42 7·31	3·47 6·57	3·47 7·31	3·04 3·98	11·115
Potash (available)	·022	..	..	..	..	..	..	..	..
Phosphoric (available)	·014	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·112	0·064	0·056	0·07	0·059	0·088	0·071	0·039	0·101

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	FEROZEPUR					JULLUNDUR		LAHORE	
DESCRIPTION		1st ft.	2nd ft.	1st ft.	2nd ft.				
Number	127	128	129	130	131	132	133	134	135
Mechanical.									
Fine gravel	*nil*	*nil*	0·07	0·21	0·14	*nil*	*nil*	*nil*	*nil*
Coarse sand	12·64	3·82	3·58	2·40	1·84	33·46	1·82	3·88	2·01
Fine sand	15·36	40·47	35·30	41·17	27·63	36·56	6·22	46·08	45·63
Silt	19·90	20·30	26·03	20·04	25·98	11·82	17·65	20·64	22·88
Fine silt	34·71	15·76	18·32	17·68	24·16	9·00	38·28	12·16	12·16
Clay	14·74	13·60	13·76	13·92	15·52	6·90	28·08	12·48	15·04
Chemical.									
Potash as K_2O	0·867	0·775	0·786	0·721	0·763	0·786	1·459	0·790	0·930
Phosphoric acid as P_2O_5	0·287	0·206	0·225	0·225	0·209	0·211	0·160	0·128	0·102
Lime as CaO	1·180	4·71	5·61	5·08	6·09	..	..	0·960	1·240
Magnesia as MgO	1·565	1·94	1·67	1·88	1·53	..	..	1·280	1·190
Iron and Aluminium (Fe_2O_3) Al_2O_3	12·843	4·24 5·83	4·32 5·98	4·16 5·49	4·69 5·97	..	..	10·822	11·518
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·053	0·078	0·066	0·066	0·065	0·046	0·164	0·034	0·044

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	SHEIKHUPURA								
DESCRIPTION									
Number	136	137	138	139	140	141	142	143	144
Mechanical.									
Fine gravel	·39	·52	..	..	..	..	..	..	..
Coarse sand	15·74	23·20	..	..	..	..	..	..	..
Fine sand	36·73	36·24	..	..	..	..	..	..	..
Silt	16·18	17·58	..	..	..	..	..	..	..
Fine silt	9·92	8·00	..	..	..	..	..	..	..
Clay	16·96	7·52	..	..	..	..	..	..	..
Chemical.									
Potash as K_2O	0·710	0·290	0·205	0·165	0·888	0·329	0·825	1·142	0·196
Phosphoric acid as P_2O_5	0·128	0·114	0·158	0·147	0·093	0·131	0·196	0·254	0·138
Lime as CaO	1·330	3·250	0·812	0·588	0·658	0·735	2·910	0·784	0·497
Magnesia as MgO	0·925	1·940	1·09	0·940	1·310	0·850	1·430	1·520	0·750
Iron and Aluminium (Fe_2O_3) Al_2O_3	11·022	5·736	1·98 2·26	1·78 3·98	3·26 5·72	1·86 3·05	4·33 6·11	4·44 2·18	1·28 2·81
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·036	0·042	0·021	0·030	0·033	0·028	0·077	0·064	0·023

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	SHEIKHUPURA					GUJRAT			MONTGOMERY
DESCRIPTION									
Number	145	146	147	148	149	150	151	152	153
Mechanical.									
Fine gravel	..	..	..	..	..	*nil*	*nil*	*nil*	·22
Coarse sand	..	..	..	..	..	14·79	59·77	8·61	·76
Fine sand	..	..	..	..	..	26·83	20·49	29·64	39·42
Silt	..	..	..	..	..	25·15	7·25	26·19	15·08
Fine silt	..	..	..	..	..	12·80	2·24	17·92	19·60
Clay	..	..	..	..	..	14·08	4·64	13·44	17·60
Chemical.									
Potash as K_2O	0·791	0·330	0·536	0·727	0·899	0·760	0·372	0·702	..
Phosphoric acid as P_2O_5	0·084	0·115	0·118	0·198	0·148	0·225	0·159	0·290	..
Lime as CaO	1·386	1·547	0·609	2·450	2·303	1·230	·835	1·210	1·68
Magnesia as MgO	1·30	1·66	0·88	1·15	2·46	1·600	1·000	1·020	0·25
Iron and Aluminium (Fe_2O_3) Al_2O_3	3·26 5·74	4·10 6·30	1·94 3·41	4·42 5·43	3·82 7·36	10·715	6·741	10·420	11·91
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·043	0·060	0·031	0·097	0·090	0·073	0·007	0·082	..

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	MONTGOMERY								
DESCRIPTION									
Number	154*	155	156	157	158	159	160	161	162
Mechanical.									
Fine gravel	..	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	1·20	1·00
Coarse sand	..	2·60	2·81	..	2·06	2·44	1·35	3·97	2·54
Fine sand	..	12·85	48·62	..	50·59	59·27	49·12	57·43	46·43
Silt	..	20·30	23·43	..	16·89	11·89	24·29	11·26	20·63
Fine silt	..	35·60	11·84	..	16·47	14·99	12·29	15·60	13·85
Clay	..	25·12	10·88	..	12·40	11·40	11·44	11·54	12·43
Chemical.									
Potash as K_2O	..	..	0·780	0·950	0·81	0·72	0·63	0·76	0·78
Phosphoric acid as P_2O_5	..	..	0·150	0·288	0·187	0·210	0·226	0·208	0·185
Lime as CaO	..	..	3·160	4·800	5·63	5·14	3·64	6·12	5·05
Magnesia as MgO	..	..	2·010	2·900	1·46	1·92	1·89	1·82	1·94
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	..	9·300	8·830	3·68 5·20	3·20 5·27	4·00 4·54	3·76 4·47	3·96 4·97
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	..	..	0·024	0·037	0·027	0·033	0·054	0·034	0·048

* Cancelled.

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	MONTGOMERY								
DESCRIPTION	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.
Number	163	164	165	166	167	168	169	170	171
Mechanical.									
Fine gravel	0·04	0·04	*nil*	0·03	0·03	0·07	0·07	0·1	0·03
Coarse sand	2·51	2·56	1·91	1·08	2·07	2·10	2·31	2·60	0·46
Fine sand	56·32	52·47	43·19	38·07	55·60	51·56	53·97	54·36	45·90
Silt	19·16	18·52	26·16	28·06	17·42	18·90	18·89	17·29	19·89
Fine silt	10·72	12·48	12·31	16·98	11·79	12·73	13·12	12·66	15·94
Clay	11·72	13·48	14·59	15·87	12·78	14·72	11·65	10·24	18·72
Chemical.									
Potash as K_2O	0·90	0·85	1·04	1·05	0·77	0·80	0·84	0·77	0·99
Phosphoric acid as P_2O_5	0·207	0·182	0·200	0·157	0·205	0·170	0·183	0·153	0·212
Lime as CaO	3·05	3·57	4·26	5·68	3·00	3·88	4·17	5·56	3·88
Magnesia as MgO	1·83	1·82	1·04	1·09	1·79	1·79	1·78	1·77	2·04
Iron and Aluminium (Fe_2O_3) Al_2O_3	4·20 4·83	4·28 5·19	4·40 5·55	4·44 5·79	4·12 4·66	4·40 4·53	4·04 4·29	4·10 4·74	4·60 5·21
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·024	0·038	0·039	0·016	0·028	0·032	0·040	0·035	0·038

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	MONTGOMERY	LYALLPUR							
DESCRIPTION	2nd ft.								
Number	172	173	174	175	176	177	178	179	180
Mechanical.									
Fine gravel	0·04	0·34	..	..	..	..	..	..	..
Coarse sand	0·96	8·24	..	..	..	..	..	..	..
Fine sand	47·48	41·32	..	..	..	..	..	..	..
Silt	19·41	18·63	..	..	..	..	..	..	..
Fine silt	13·70	18·70	..	..	..	..	..	..	..
Clay	18·05	10·95	..	..	..	..	..	..	..
Chemical.									
Potash as K_2O	1·12	0·827	1·250	1·030	1·030	1·190	1·200	0·960	0·780
Phosphoric acid as P_2O_5	0·187	0·351	0·210	0·160	0·150	0·200	0·180	0·140	0·140
Lime as CaO	4·28	6·280	..	..	..	..	..	..	..
Magnesia as MgO	2·12	0·885	..	..	..	..	..	..	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	4·64 5·54	9·989	..	..	..	..	..	..	..
Potash (available)	..	..	0·009	0·028	0·023	0·012	0·023	0·024	0·020
Phosphoric (available)	..	..	0·048	0·049	0·053	0·074	0·048	0·030	0·024
NITROGEN (% on air dried soil)	0·027	0·041	0·043	0·038	0·038	0·052	0·047	0·038	0·026

TABLE 1—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	LYALLPUR					SHAHPUR			
						SARGODHA			
DESCRIPTION		1st ft.	2nd ft.	1st ft.	2nd ft.				
Number	181	182	183	184	185	186	187	188	189
Mechanical.									
Fine gravel	..	*nil*	*nil*	*nil*	*nil*	0·06	*nil*	*nil*	..
Coarse sand	..	13·01	7·60	23·03	25·55	17·63	10·89	13·91	..
Fine sand	..	43·80	46·77	46·22	44·73	45·07	44·32	39·39	..
Silt	..	14·65	15·46	11·35	8·85	15·63	13·51	17·86	..
Fine silt	..	13·20	16·21	9·15	7·84	8·00	14·24	11·20	..
Clay	..	15·60	14·40	10·14	10·64	7·04	13·92	12·64	..
Chemical.									
Potash as K_2O	·760	0·500	0·600	0·550	0·600	0·956	0·743	..	..
Phosphoric acid as P_2O_5	·140	0·227	0·210	0·224	0·230	0·215	1·611	0·281	..
Lime as CaO	..	4·27	4·56	1·64	1·87	3·430	3·450	3·220	16·98
Magnesia as MgO	..	1·55	1·59	1·16	1·31	1·860	1·290	1·710	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	2·38 5·28	2·52 5·57	2·63 4·40	2·27 4·30	9·895	8·024	8·689	..
Potash (available)	0·029	..	..	..	..	..	..	..	0·164
Phosphoric (available)	0·012	..	..	..	..	..	..	..	0·007
NITROGEN (% on air dried soil)	·049	0·042	0·043	0·029	0·027	0·033	0·037	0·042	0·014

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	SHAHPUR								
DESCRIPTION	SARGODHA							MONA	
Number	190	191	192	193	194	195	196	197	198
Mechanical.									
Fine gravel	..	..	..	..	..	..	..	*nil*	0·02
Coarse sand	..	..	..	..	..	..	..	3·59	2·93
Fine sand	..	..	..	..	..	..	..	23·36	18·29
Silt	..	..	..	..	..	..	..	28·46	25·16
Fine silt	..	..	..	..	..	..	..	18·48	22·88
Clay	..	..	..	..	..	..	..	21·12	25·60
Chemical.									
Potash as K_2O	..	..	..	..	..	..	..	0·884	0·956
Phosphoric acid as P_2O_5	..	..	..	..	..	..	..	0·154	0·144
Lime as CaO	..	..	..	..	..	..	..	1·78	1·88
Magnesia as MgO	..	..	..	..	..	..	..	2·01	1·80
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	..	..	..	..	..	..	2·64 10·19	5·68 8·59
Potash (available)	0·033	0·067	0·078	0·035	0·057	0·036	0·035	..	..
Phosphoric (available)	0·067	0·161	0·028	0·031	0·009	0·057	0·059	..	..
NITROGEN (% on air dried soil)	..	..	..	..	..	..	..	0·076	0·049

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	SHAHPUR								
	MONA							SARGODHA.	
DESCRIPTION	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.		1st ft.	2nd ft.
Number	199	200	201	202	203	204	205	206	207
Mechanical.									
Fine gravel	0·13	0·01	0·52	0·40	*nil*	0·01	0·44	0·16	*nil*
Coarse sand	7·90	8·01	43·46	43·31	5·41	4·14	5·23	8·08	5·65
Fine sand	25·21	18·10	21·14	20·32	24·58	22·33	22·39	35·50	36·46
Silt	18·56	17·38	11·77	10·33	24·39	22·37	24·57	21·05	21·10
Fine silt	12·96	20·15	7·60	10·08	17·76	22·96	24·27	15·36	15·04
Clay	28·64	32·32	10·72	9·44	23·69	23·84	22·08	15·84	15·36
Chemical.									
Potash as K_2O	0·549	0·901	0·397	0·343	1·079	0·901	1·02	0·693	0·893
Phosphoric acid as P_2O_5	0·165	0·171	0·149	0·121	0·233	0·239	0·238	0·233	0·190
Lime as CaO	1·05	1·84	6·17	4·62	1·22	1·15	3·20	2·84	3·26
Magnesia as MgO	0·75	1·58	1·46	1·40	1·95	1·77	1·57	1·62	1·71
Iron and Aluminium (Fe_2O_3) Al_2O_3	4·72 8·53	5·72 8·53	3·44 4·68	3·64 4·10	5·38 7·96	5·77 8·76	3·89 8·25	4·44 6·86	4·90 6·88
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·085	0·068	0·053	0·081	0·043	0·061	0·056	0·055	0·045

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	SHAHPUR						JHANG		MULTAN
	SARGODHA								
DESCRIPTION	1st ft.	2nd ft.	1st ft.	2nd ft.	1st ft.	2nd ft.			
Number	208	209	210	211	212	213	214	215	216
Mechanical.									
Fine gravel	0·28	1·08	0·09	0·43	0·12	*nil*	*nil*	*nil*	*nil*
Coarse sand	3·52	2·82	42·50	38·43	7·18	3·41	9·44	8·00	7·36
Fine sand	27·74	21·22	26·03	24·78	24·09	22·56	12·00	12·64	14·92
Silt	23·10	20·83	10·90	12·58	30·82	33·74	20·80	22·69	22·58
Fine silt	19·52	21·04	8·64	10·08	19·04	19·44	48·73	46·31	47·69
Clay	20·96	26·40	8·00	8·43	16·00	16·96	5·58	4·90	3·78
Chemical.									
Potash as K_2O	0·724	1·057	0·547	0·495	0·689	0·585	0·847	0·837	0·442
Phosphoric acid as P_2O_5	0·264	0·176	0·182	0·208	0·156	0·207	0·640	0·622	0·533
Lime as CaO	3·06	4·18	4·28	5·43	7·30	9·20	4·400	4·160	4·520
Magnesia as MgO	1·65	2·01	1·34	1·45	2·24	2·49	1·600	0·770	1·320
Iron and Aluminium (Fe_2O_3) Al_2O_3	4·85 7·24	5·72 8·27	3·76 5·13	3·79 5·10	5·05 6·10	4·88 5·63	8·445	9·758	8·152
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·067	0·060	0·039	0·040	0·071	0·046	0·053	0·047	0·053

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	MULTAN								
DESCRIPTION		Ghasree	Ghasra	Ratti	Ratta			1st ft.	2nd ft.
Number	217	218	219	220	221	222	223	224	225
Mechanical.									
Fine gravel	0·12	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*	*nil*
Coarse sand	1·10	4·54	1·93	2·29	·87	15·51	33·08	·40	·30
Fine sand	14·22	52·34	37·36	27·84	34·08	52·45	50·70	16·74	11·56
Silt	31·79	15·09	26·08	29·20	35·39	12·60	6·78	6·99	5·05
Fine silt	30·40	17·04	24·74	26·72	22·83	5·68	4·48	7·84	7·12
Clay	14·72	10·32	11·52	11·05	9·09	8·64	3·44	63·60	71·04
Chemical.									
Potash as K_2O	0·717	..	..	..	..	..	..	..	..
Phosphoric acid as P_2O_5	0·242	..	..	..	..	..	..	..	..
Lime as CaO	3·060	..	..	..	..	..	..	..	..
Magnesia as MgO	1·230	..	..	..	..	..	..	..	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	10·738	..	..	..	..	..	..	..	..
Potash (available)	..	0·019	0·050	0·043	0·034	..	..	..	..
Phosphoric (available)	..	0·051	0·024	0·031	0·032	..	..	..	..
NITROGEN (% on air dried soil)	0·064	0·114	0·127	0·134	0·139	..	..	..	..

TABLE I—*contd.*

Analyses of the Punjab Soils—contd.

LOCALITY	MULTAN				MUZAFFARGARH		DERA GHAZI KHAN		BAHAWALPUR
DESCRIPTION	1st ft.	2nd ft.							
Number	226	227	228	229	230	231	232	233	234
Mechanical.									
Fine gravel	0·24	*nil*	..	..	*nil*	*nil*	*nil*	*nil*	0·66
Coarse sand	1·85	3·17	..	..	5·01	4·08	18·03	40·82	2·45
Fine sand	32·01	24·64	..	..	33·52	31·47	56·12	18·72	42·15
Silt	8·95	10·29	..	..	20·79	22·02	4·71	9·93	26·12
Fine silt	10·88	10·80	..	..	20·32	12·32	6·08	10·24	12·80
Clay	39·04	43·52	..	..	20·32	13·28	9·28	16·48	8·96
Chemical									
Potash as K_2O	..	..	0·675	0·808	0·861	0·822	0·687	0·802	..
Phosphoric acid as P_2O_5	..	..	0·169	0·159	0·195	0·223	0·670	1·355	..
Lime as CaO	..	..	2·786	2·786	5·090	6·015	9·980	6·030	..
Magnesia as MgO	..	..	1·56	1·63	1·948	1·991	1·170	1·730	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	..	4·46 5·99	4·92 6·14	11·745	10·737	9·155	8·295	..
Potash (available)	..	..	..	..	..	..	..	..	..
Phosphoric (available)	..	..	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	..	..	..	..	0·043	0·045	0·026	0·040	..

TABLE I (a).

The Punjab Soils.

SUBSOILS.

Soil No.	Nitrogen	Organic matter	Lime CaO	Potash K_2O	Phosphates P_2O_5	Remarks
			Per cent. on air dried material			
			GURDASPUR.			
48	0·059	3·21	0·56	0·52	0·10	Soil.
49	0·066	3·83	0·28	0·57	0·11	Subsoil.
50	0·075	2·16	0·84	0·43	0·08	Soil.
51	0·043	2·82	0·85	0·53	0·06	Subsoil.
52	0·033	1·78	0·41	0·48	0·16	Soil.
53	0·066	1·87	0·39	0·44	0·14	Subsoil.
			RAWALPINDI			
54	0·067	3·63	11·44	0·70	0·20	Soil.
55	0·086	4·26	10·13	0·59	0·18	Subsoil.
56	0·041	2·44	11·20	0·50	0·21	Soil.
57	0·048	2·71	11·39	0·51	0·21	Subsoil.
58	0·059	2·90	9·07	0·30	0·16	Soil.
59	0·046	4·33	9·55	0·45	0·17	Subsoil.
			ATTOCK.			
60	0·053	5·17	1·95	0·77	0·17	Soil.
31	0·050	6·31	1·99	0·88	0·19	Subsoil.
63	0·071	9·94	12·81	0·55	0·10	Soil.
84	0·055	9·27	12·88	0·46	0·15	Subsoil.
66	0·037	5·62	7·71	0·42	0·11	Soil.
67	0·037	8·20	8·37	0·41	0·17	Subsoil.
69	0·093	6·96	8·89	0·20	0·16	Soil.

TABLE I (*a*)—*contd.*

The Punjab Soils—contd.

SUBSOILS—*contd.*

Soil No.	Nitrogen	Organic matter	Lime Ca O	Potash K_2O	Phosphates P_2O_5	Remarks
			Per cent. on air dried material			
			ATTOCK—*contd.*			
70	0·054	6·31	2·39	0·62	0·10	Subsoil.
72	0·047	5·86	5·89	0·52	0·10	Soil.
73	0·049	6·64	4·51	0·54	0·09	Subsoil.
75	0·090	9·65	9·14	0·68	0·37	Soil.
76	0·062	10·02	8·85	0·72	0·28	Subsoil.
78	0·069	8·76	8·20	0·63	0·26	Soil.
79	0·067	10·57	10·92	0·49	0·16	Subsoil.
81	0·066	7·33	12·18	0·52	0·20	Soil.
82	0·064	9·21	11·31	0·80	0·10	Subsoil.
84	0·056	7·51	13·20	0·87	0·12	Soil.
85	0·042	8·25	16·60	0·84	0·08	Subsoil .
87	0·087	10·31	5·10	0·76	0·04	Soil.
88	0·046	8·67	6·16	0·81	0·04	Subsoil.
			HISSAR.			
97	0·074	3·46	2·02	0·68	0·32	Soil.
98	0·042	3·58	2·36	0·63	0·32	Subsoil.
99	0·081	3·43	2·65	0·67	0·24	Soil.
100	0·054	4·67	2·61	0·59	0·23	Subsoil.
101	0·063	3·27	1·37	0·74	0·19	Soil.
102	0·048	4·84	1·12	0·77	0·17	Subsoil.
103	0·038	2·85	1·16	0·57	0·22	Soil.
104	0·043	2·89	1·31	0·38	0·21	Subsoil.

TABLE I(*a*)—*contd.*

The Punjab Soils—contd.

SUBSOILS—*contd*

Soil No.	Nitrogen	Organic matter	Lime CaO	Potash K_2O	Phosphates P_2O_5	Remarks
			Per cent. on air dried material			
			KARNAL.			
119	0·064	..	0·58	0·65	0·13	Soil.
120	0·056	·46	0·44	0·65	0·10	Subsoil.
121	0·070	3·52	0·43	0·67	0·12	Soil.
122	0·059	3·18	0·78	0·91	0·14	Subsoil.
123	0·088	3·12	0·84	1·10	0·14	Soil.
124	0·071	4·28	0·63	0·88	0·13	Subsoil.
			FEROZEPUR.			
128	0·078	5·86	4·71	0·78	0·21	Soil.
129	0·066	6·57	5·61	0·79	0·23	Subsoil.
130	0·066	6·13	5·08	0·72	0·23	Soil.
131	0·065	7·43	6·09	0·76	0·21	Subsoil.
			MONTGOMERY.			
163	0·034	1·73	3·05	0·90	0·21	Soil.
164	0·038	0·95	3·57	0·85	0·18	Subsoil.
165	0·039	1·57	4·26	1·04	0·20	Soil.
166	0·016	3·45	5·68	1·05	0·16	Subsoil.
167	0·028	1·68	3·00	0·77	0·21	Soil.
168	0·032	1·10	3·88	0·80	0·17	Subsoil.
169	0·040	2·42	4·17	0·84	0·18	Soil.
170	0·035	1·75	5·56	0·77	0·15	Subsoil.
171	0·038	1·58	3·88	0·99	0·21	Soil.
172	0·027	3·32	4·28	1·12	0·19	Subsoil.

Table I(*a*)—*concld.*

The Punjab Soils—concld.

Subsoils—*concld.*

Soil No.	Nitrogen	Organic matter	Lime CaO	Potash K_2O.	Phosphates P_2O_5	Remarks
			Per cent. on air dried material.			
			Lyallpur.			
182	0·042	3·04	4·27	0·50	0·23	Soil.
183	0·043	0·80	4·56	0·60	0·21	Subsoil.
184	0·029	1·24	1·64	0·55	0·22	Soil.
185	0·027	0·87	1·87	0·60	0·23	Subsoil.
			Shahpur.			
197	0·076	5·60	1·78	0·88	0·15	Soil.
198	0·049	..	1·88	0·96	0·14	Subsoil.
199	0·085	5·45	1·05	0·55	0·17	Soil.
200	0·068	6·46	1·84	0·90	0·17	Subsoil.
201	0·053	3·40	6·17	0·40	0·15	Soil.
202	0·081	6·12	4·62	0·34	0·12	Subsoil.
203	0·043	4·01	1·22	1·08	0·23	Soil.
204	0·081	5·17	1·55	0·90	0·24	Subsoil.
206	0·055	4·74	2·84	0·69	0·23	Soil.
207	0·045	6·70	3·26	0·89	0·19	Subsoil.
208	0·067	7·00	3·06	0·72	0·26	Soil.
209	0·060	1·92	4·18	1·06	0·17	Subsoil.
210	0·039	3·39	4·28	0·55	0·18	Soil.
211	9·040	2·31	5·43	0·50	0·21	Subsoil.
212	0·071	5·89	7·30	0·69	0·16	Soil.
213	0·046	4·82	9·20	0·59	0·21	Subsoil.

TABLE II.

The Punjab Soils.

SOIL ANALYSES.

(**Water Extract 10 per cent.**)

Soil No.	Total solids	Carbonates as $Na_2 Co_3$	Bicarbonates as $NaH Co_3$	Chlorides as $Na Cl$	Sulphates as $Na_2 So_4$
Per cent. on air dried material					
AMBALA.					
10	0·110	*Nil*	0·084	0·060	*Nil*
11	0·060	,,	0·067	0·007	,,
12	0·080	,,	0·084	0·005	,,
RAWALPINDI.					
54	0·131	*Nil*	0·084	0·019	*Nil*
55	0·129	,,	0·084	0·012	,,
56	0·188	,,	0·103	0·020	0·073
57	0·223	,,	0·124	0·034	0·092
58	0·301	,,	0·239	0·071	*Nil*
59	0·078	,,	0·076	0·008	,,
ATTOCK.					
60	0·562	*Nil*	0·235	0·105	0·233
61	0·516	,,	0·202	0·082	0·202
62	0·350	,,	0·185	0·105	0·089
63	0·452	,,	0·185	0·094	0·101
64	0·240	,,	0·185	0·070	0·074
65	0·200	,,	0·185	0·070	0·074
66	0·210	,,	0·202	0·058	0·075
67	0·320	,,	0·220	0·058	0·107
68	0·240	,,	0·220	0·058	0·087
69	0·320	,,	0·220	0·070	0·098

TABLE II—*contd.*

The Punjab Soils—contd.

SOIL ANALYSES—*contd.*

(**Water Extract 10 per cent.**)

Soil No.	Total solids	Carbonates as $Na_2 Co_3$	Bicarbonates as $NaH Co_3$	Chlorides as $Na Cl$	Sulphates as $Na_2 So_4$
		Per cent. on air dried material			
		ATTOCK—*contd.*			
70	0·310	*Nil*	0·185	0·070	0·072
71	0·376	,,	0·202	0·070	0·073
72	0·296	,,	0·286	0·045	0·063
73	0·260	,,	0·269	0·058	0·064
74	0·320	,,	0·269	0·058	0·052
75	0·478	,,	0·269	0·081	0·064
76	0·412	,,	0·302	0·081	0·124
77	0·510	,,	0·252	0·058	0·158
78	0·284	,,	0·252	0·058	0·064
79	0·224	,,	0·252	0·058	0·104
80	0·290	,,	0·269	0·081	0·090
81	0·320	,,	0·269	0·046	0·044
82	0·400	,,	0·252	0·070	0·070
83	0·240	,,	0·252	0·047	0·055
84	0·280	,,	0·252	0·047	0·064
85	0·440	,,	0·252	0·070	0·085
86	0·488	,,	0·252	0·055	0·147
87	0·298	,,	0·202	0·046	0·049
88	0·377	,,	0·218	0·093	0·066
89	0·364	,,	0·235	0·070	0·061
90	0·320	,,	0·202	0·035	0·048
91	0·426	,,	0·286	0·082	0·051

TABLE II—*contd.*

The Punjab Soils—contd.

SOIL ANALYSES—*contd.*

(Water Extract 10 per cent.)

Soil No.	Total solids	Carbonates as $Na_2 Co_3$	Bicarbonates as $Na HCo_3$	Chlorides as $Na Cl$	Sulphates as $Na_2 So_4$
			Per cent. on air dried material		
			HISSAR.		
97	0·534	*Nil*	0·373	0·034	0·063
98	0·535	,,	0·415	0·034	0·038
99	0·482	,,	0·380	0·017	0·023
100	0·458	,,	0·363	0·045	0·035
			KARNAL.		
119	0·069	*Nil*	0·067	0·010	*Nil*
120	0·127	,,	0·050	0·005	0·038
121	0·070	,,	0·034	0·002	*Nil*
122	0·078	,,	0·034	0·015	,,
123	0·117	,,	0·050	0·023	0·029
124	0·093	,,	0·050	0·005	0·006
			FEROZEPUR.		
128	0·303	*Nil*	0·118	0·060	0·044
129	0·210	,,	0·118	0·015	0·080
130	0·270	,,	0·101	0·012	0·014
131	0·301	,,	0·101	0·024	0·021
			MONTGOMERY.		
158	0·381	*Nil*	0·235	0·055	0·057
159	0·317	,,	0·219	0·064	*Nil*
160	0·321	,,	0·199	0·055	,,

TABLE II—*concld.*

The Punjab Soils—concld.

SOIL ANALYSES—*concld.*

(Water Extract 10 per cent.)

Soil No.	Total solids	Carbonates as $Na_2 Co_3$	Bicarbonates as $NaH Co_3$	Chlorides as $Na Cl$	Sulphates as $Na_2 So_4$
			Per cent. on air dried material		
			MONTGOMERY—*contd.*		
161	0·276	*Nil*	0·190	0·041	*Nil*
162	0·288	,,	0·185	0·035	,,
			SHAHPUR (MONA).		
197	0·073	*Nil*	0·050	0·007	*Nil*
198	0·065	,,	0·057	0·012	,,
199	0·174	,,	0·050	0·023	0·075
200	0·067	,,	0·050	0·007	0·020
201	0·126	,,	0·076	0·012	*Nil*
202	0·206	,,	0·071	0·014	0·087
203	0·111	,,	0·067	0·007	*Nil*
204	0·093	,,	0·067	0·013	0·008
			SHAHPUR (SARGODHA).		
206	0·109	*Nil*	0·084	0·105	*Nil*
207	0·330	,,	0·260	0·054	,,
208	0·392	,,	0·252	0·095	,,
209	0·108	,,	0·076	0·013	,,
210	0·341	,,	0·252	0·066	,,
211	0·094	,,	0·076	0·007	,,
212	0·137	,,	0·100	0·016	,,
213	0·138	,,	0·084	0·016	,,

TABLE III.

The Punjab Soils.

MECHANICAL ANALYSES OF LYALLPUR SUBSOIL DOWN TO WATER TABLE.

No.	Description	Fine gravel	Coarse sand	Fine sand	Silt	Fine silt	Clay
			Per cent. on air dried earth				
1	1st and 2nd foot of soil.	0·15	6·95	36·21	18·10	16·40	8·58
2	3rd and 4th foot of soil.	0·16	2·05	37·81	22·76	16·62	8·66
3	5th and 6th foot of soil.	0·39	1·52	43·24	22·43	15·45	7·32
4	7th and 8th foot of soil.	*Nil*	2·02	47·35	21·56	14·05	6·92
5	9th and 10th foot of soil.	0·01	2·79	51·32	19·04	11·70	6·46
6	11th and 12th foot of soil.	*Nil*	13·93	77·88	2·98	4·00	Trace
7	13th and 14th foot of soil.	,,	27·91	64·54	2·78	4·00	1·13
8	15th and 16th foot of soil.	,,	44·32	47·78	2·93	4·20	Trace
9	17th and 18th foot of soil.	,,	59·39	29·14	4·44	0·54	1·35
10	19th and 20th foot of soil.	,,	28·16	62·67	2·58	4·60	1·09
11	21st and 22nd foot of soil.	,,	42·66	46·24	5·43	4·50	1·26
12	23rd and 24th foot of soil.	,,	63·03	29·06	3·70	0·27	0·59
13	25th and 26th foot of soil.	,,	64·65	27·03	3·62	3·60	0·58
14	27th and 28th foot of soil.	,,	62·39	30·99	3·03	3·20	*Nil*
15	29th and 30th foot of soil.	,,	78·16	17·15	2·08	3·40	,,
16	31st and 32nd foot of soil.	,,	60·05	29·40	4·29	0·44	1·11

TABLE III—*contd.*

The Punjab Soils—contd.

MECHANICAL ANALYSES OF LYALLPUR SUBSOIL DOWN TO WATER TABLE—*contd.*

No.	Description	Fine gravel	Coarse sand	Fine sand	Silt	Fine silt	Clay
		Per cent. on air dried earth					
17	33rd and 34th foot of soil.	..	..	..	..	..	..
18	35th and 36th foot of soil.	*Nil*	3·38	7·07	28·23	38·20	19·20
19	37th and 38th foot of soil.	,,	64·95	23·00	4·20	6·90	*Nil*
20	39th and 40th foot of soil.	,,	42·94	44·94	5·35	0·47	1·20
21	41st and 42nd foot of soil.	0·55	56·80	31·24	3·06	5·00	1·62
22	43rd and 44th foot of soil.	0·40	44·96	42·53	5·50	0·52	1·48
23	45th and 46th foot of soil.	*Nil*	37·61	40·98	5·59	4·80	1·56
24	47th and 48th foot of soil.	0·42	40·76	38·32	5·29	7·40	4·69
25	49th and 50th foot of soil.	0·26	64·99	25·52	2·51	7·20	0·88
26	51st and 52nd foot of soil.	*Nil*	79·74	12·23	1·52	2·20	*Nil*
27	53rd and 54th foot of soil.	0·48	43·18	16·13	7·98	17·80	4·24
28	55th and 56th foot of soil.	1·55	48·06	31·10	7·95	10·10	3·02
29	57th and 58th foot of soil.	0·08	0·83	39·80	33·89	18·00	6·64
30	59th and 60th foot of soil.	0·06	5·12	34·19	30·99	22·00	7·20
31	61st and 62nd foot of soil.	*Nil*	44·03	39·55	7·04	8·30	*Nil*
32	63rd and 64th foot of soil.	,,	65·71	26·06	3·70	0·44	0·58
33	65th and 66th foot of soil.	,,	43·44	32·52	5·45	6·40	1·84

TABLE IV.

The Punjab Soils.

NITROGEN AND ORGANIC MATTER.

(Percentage on air dried soil.)

Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition
		KANGRA.	
1	0·05	..	..
2	0·15	..	..
3	0·076	..	..
4	0·05	..	..
5	0·11	..	..
6	0·11	8·64	0·013
7	0·10	2·17	0·046
		AMBALA.	
8	0·02	2·09	0·010
9	0·054	3·09	0·018
10	0·061	3·11	0·020
11	0·039	2·41	0·016
12	0·053	3·43	0·015
13	0·039	2·05	0·019
14	0·041	2·54	0·016
		HOSHIARPUR.	
15	0·053	3·24	0·016
16	0·055	..	..
		GURDASPUR.	
17	0·075	2·47	0·030
18	0·058	5·02	0·012
19	0·033	2·85	0·012
20	0·047	5·11	0·009
21	0·032	2·13	0·015
22	0·048	3·12	0·015
23	0·045	1·18	0·038
24	0·046	2·46	0·019
25	0·049	2·05	0·024
26	0·046	1·08	0·043
27	0·048	..	..
28	0·063	..	..
29	0·058	2·4	0·024
30	0·052	..	..
31	0·078	3·59	0·022
32	0·075	3·05	0·025
33	0·082	1·57	0·033
34	0·059	..	..
35	0·078	..	..
36	0·048	..	..
37	0·057	..	..

TABLE IV—*contd.*

The Punjab Soils—contd.

NITROGEN AND ORGANIC MATTER—*contd.*

(Percentage on air dried soil.)

Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition	Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition
	GURDASPUR—*contd.*				ATTOCK—*contd.*		
38	0·085	..	..	69	0·093	6·96	0·013
39	0·070	..	..	72	0·047	5·86	0·008
40	0·050	..	..	75	0·090	9·65	0·009
41	0·056	..	..	78	0·069	8·76	0·008
42	0·055	..	..	81	0·066	7·31	0·009
43	0·063	..	..	84	0·056	7·51	0·008
44	0·050	..	..	87	0·087	10·31	0·008
45	0·062	..	..	90	0·052	10·06	0·005
46	0·053	..	..				
48	0·059	3·21	0·018		HISSAR.		
50	0·075	2·16	0·035	91	0·053	4·46	0·012
52	0·033	1·78	0·019	92	0·039	1·30	0·030
	RAWALPINDI.			93	0·042	4·10	0·010
				94	0·053	6·07	0·009
54	0·067	3·63	0·018	95	0·039	5·19	0·008
56	0·041	2·44	0·017	96	0·049	5·15	0·010
58	0·059	2·90	0·020	97	0·074	3·46	0·021
	ATTOCK.			99	0·081	3·43	0·024
60	0·053	5·17	0·010	101	0·063	3·27	0·019
63	0·071	9·94	0·007	103	0·038	2·85	0·013
66	0·037	5·62	0·007	105	0·048	1·79	0·027

TABLE IV—*contd.*

The Punjab Soils—contd.

NITROGEN AND ORGANIC MATTER—*contd.*

(Percentage on air dried soil.)

Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition
	HISSAR—*contd.*		
196	0·054	2·49	0·022
107	0·050	2·04	0·025
108	0·042	3·80	0·011
109	0·030	2·65	0·011
	KARNAL.		
110	0·051	1·82	0·028
111	0·047	2·09	0·023
112	0·066	..	..
113	0·024	..	..
114	0·074	..	..
115	0·011	..	..
116	0·080	..	..
117	0·074	..	..
118	0·112	..	..
119	0·064	..	..
121	0·070	3·52	0·020
123	0·088	3·12	0·028
125	0·039	3·66	0·011

Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition
	FEROZEPUR.		
126	0·101	6·27	0·016
127	0·053	2·65	0·020
128	0·078	5·86	0·013
130	0·066	6·13	0·011
	JULLUNDUR.		
132	0·046	2·26	0·020
133	0·164	7·23	0·023
	LAHORE.		
134	0·034	4·76	0·007
135	0·044	2·28	0·019
	SHEIKHUPURA.		
136	0·036	4·07	0·009
137	0·042	6·92	0·006
138	0·021	0·51	0·004
139	0·030	0·96	0·003
140	0·033	2·17	0·015
141	0·028	0·54	0·005
142	0·077	4·74	0·016
143	0·064	3·99	0·016

TABLE IV—*contd.*

The Punjab Soils—contd.

NITROGEN AND ORGANIC MATTER—*contd.*

(Pecentage on air dried soil.)

Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition
	SHEIKHUPURA—*contd.*		
144	0·023	(?)0·10	..
145	0·043	3·01	0·014
146	0·060	2·46	0·024
147	0·031	0·92	0·003
148	0·097	2·25	0·043
149	0·090	2·85	0·032
	UJRAT.		
150	0·073	6·35	0·012
151	0·070	5·61	0·013
152	0·082	4·20	0·020
	MONTGOMERY.		
154	0·024	2·42	0·010
155	0·044	2·99	0·014
156	0·024	..	..
157	0·037	..	..
158	0·027	1·78	0·015
159	0·033	1·52	0·022
160	0·054	2·66	0·020
161	0·034	1·22	0·028
162	0·048	2·53	0·019
	MONTGOMERY—*contd.*		
163	0·034	1·73	0·020
165	0·038	1·57	0·024
167	0·028	1·68	0·017
169	0·040	2·42	0·017
171	0·038	1·58	0·024
	LYALLPUR.		
173	0·041	1·82	0·022
174	0·043	..	..
175	0·038	..	..
176	0·038	..	..
177	0·052	..	..
178	0·047	..	
179	0·038	..	
180	0·026	..	..
181	0·049	..	..
182	0·042	3·04	0·014
184	0·029	1·24	0·023
	SHAHPUR.		
186	0·033	6·57	0·005
187	0·037	3·13	0·012

TABLE IV—*contd.*

The Punjab Soils—contd.

NITROGEN AND ORGANIC MATTER—*contd.*

(Percentage on air dried soil.)

Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition	Soil No.	Nitrogen	Loss on ignition	Nitrogen / Loss on ignition
	SHAHPUR—*contd.*				MULTAN.		
188	0·042	5·00	0·008	216	0·053	3·67	0·014
189	0·014	..	..	217	0·064	7·65	·008
197	0·076	5·60	0·014	218	0·114	..	..
199	0·085	5·45	0·016	219	0·127	..	..
201	0·053	3·40	0·016	220	0·134	..	..
203	0·043	4·01	0·011	221	0·139	..	..
205	0·051	4·56	0·011	228	..	3·88	..
206	0·055	4·74	0·012	229	..	3·51	..
208	0·045	7·00	0·006		MUZAFFARGARH.		
210	0·060	3·39	0·018	230	0·043	..	..
212	0·040	5·89	0·007	231	0·045	6·83	0·066
	JHANG.				DERA GHAZI KHAN.		
214	0·053	3·45	0·015	232	0·026	5·78	0·004
215	0·047	5·46	0·009	233	0·040	3·81	0·011

Table V.

The Punjab Soils.

Average lime content and lime magnesia ratio for different districts of the Punjab.

District	Lime	Lime/Magnesia
Kangra	0·106	0·366
Amballa	0·98	0·94
Hoshiarpur	1·567	1·505
Gurdaspur	0·453	0·408
Rawalpindi	10·46	6·22
Attock	7·82	5·37
Hissar	1·377	1·069
Karnal	0·916	0·794
Ferozepur	4·47	2·464
Lahore	1·10	0·896
Sheikhupura	1·418	1·059
Gujrat	1·092	0·931
Montgomery	4·40	2·32
Lyallpur	3·32	3·11
Shahpur	3·63	2·16
Jhang	4·28	4·07
Multan	3·29	2·33
Muzaffargarh	5·55	2·82
Dera Ghazi Khan	8·01	4·68

TABLE VI.

The Punjab Soils.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS.

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SURFACE SOILS.			
		KANGRA.			
1	0·714	..	5·8	0·123	..
2	0·687	..	12·10	0·057	..
3	0·728	..	33·60	0·002	..
4	0·683	..	35·05	0·019	..
5	0·713	..	36·21	0·020	..
6	0·423	..	19·00	0·023	..
7	0·414	..	11·72	0·035	..
		AMBALA.			
8	0·411	..	4·80	0·085	..
9	0·974	..	19·60	0·050	..
10	0·220	2·50	6·72	0·033	·37
11	0·270	2·44	6·08	0·044	·40
12	0·290	3·07	9·92	0·029	·31
13	0·460	3·57	7·44	0·062	·48
14	0·480	3·73	10·56	0·045	·35
		HOSHIARPUR.			
15	0·599	..	8·32	0·072	..
16	0·418	..	7·04	0·059	..
		GURDASPUR.			
17	0·688	..	4·09	0·168	..
18	0·638	..	4·62	0·138	..

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SURFACE SOILS—*contd.*			
		GURDASPUR—*contd.*			
19	0·744	..	9·28	0·080	..
20	0·831	..	11·20	0·074	..
21	0·688	..	9·12	0·075	..
22	0·366	..	6·40	0·057	..
23	0·343	..	5·92	0·058	..
24	0·381	..	6·40	0·060	..
25	0·448	..	6·40	0·070	..
26	0·422	..	6·32	0·067	..
27	0·443	..	7·36	0·060	..
28	0·351	..	10·23	0·034	..
29	0·304	..	15·60	0·019	..
30	0·292	..	12·48	0·023	..
31	0·314	..	12·96	0·024	..
32	0·336	..	9·28	0·036	..
33	0·317	..	7·36	0·043	..
34	0·910	..	..	..	..
35	1·250	..	..	..	..
36	1·030	..	..	..	..
37	0·940	..	..	..	..
38	1·700	..	..	..	..
39	1·380	..	..	..	..
40	0·880	..	..	..	..

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SURFACE SOILS—*contd.*			
		GURDASPUR—*contd.*			
41	0·720	..	..	..	..
42	0·870	..	..	..	..
43	0·910	..	..	..	..
44	0·990	..	..	..	..
45	1·220	..	..	..	..
46	1·260	..	..	..	..
47	..	..	6·24	..	..
48	0·520	4·68	14·80	0·035	0·32
50	0·430	3·47	6·83	0·063	0·58
52	0·430	3·56	7·28	0·059	0·49
		RAWALPINDI.			
54	0·700	5·92	13·92	0·050	0·43
56	0·496	5·91	22·08	0·023	0·27
58	0·302	5·86	8·64	0·035	0·68
		ATTOCK.			
59	0·765	7·13	21·56	0·036	0·331
63	0·552	6·31	27·28	0·020	0·231
66	0·424	6·78	21·62	0·020	0·313
69	0·202	7·73	20·58	0·010	0·376
72	0·524	6·01	14·28	0·037	0·421
73	0·677	5·67	21·44	0·032	0·265

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
SURFACE SOILS—*contd.*					
ATTOCK—*contd.*					
78	0·632	9·29	16·80	0·038	0·553
81	0·517	7·31	19·20	0·027	0·381
84	0·872	6·98	20·28	0·043	0·344
87	0·764	7·86	14·50	0·053	0·542
90	0·761	8·80	19·20	0·040	0·458
HISSAR.					
91	1·680	..	15·52	0·108	..
92	0·495	..	13·44	0·037	..
93	0·646	..	12·80	0·050	..
94	0·717	..	14·72	0·050	..
95	0·710	..	11·20	0·063	..
96	1·297	..	33·44	0·039	..
97	0·682	4·58	16·48	0·041	0·278
99	0·666	6·74	18·40	0·036	0·366
101	0·736	6·99	26·08	0·028	0·268
103	0·572	1·36 (?)	14·24	0·040	0·096
105	0·910	4·71	15·30	0·059	0·308
106	1·010	5·88	13·28	0·076	0·442
107	0·940	5·50	15·84	0·059	0·347
108	0·640	5·59	15·66	0·041	0·357
109	0·790	4·85	16·60	0·048	0·292

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SURFACE SOILS—*contd.*			
		KARNAL.			
110	0·873	..	14·72	0·059	..
111	0·883	..	16·16	0·055	..
		HISSAR.			
119	0·650	4·86	9·44	0·069	0·515
121	0·670	5·02	16·96	0·040	0·296
123	1·100	6·57	9·44	0·117	0·696
125	0·640	3·98	7·52	0·085	0·529
		FEROZEPUR.			
126	1·090	..	14·56	0·075	..
127	0·867	..	14·74	0·059	..
128	0·775	5·83	13·60	0·057	0·429
130	0·721	5·49	13·92	0·052	0·394
		JULLUNDUR.			
132	0·786	..	6·90	0·114	..
133	1·459	..	28·08	0·052	..
		LAHORE.			
134	0·790	..	12·48	0·063	..
135	0·930	..	15·04	0·062	..

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SURFACE SOILS—*contd.*			
		SHEIKHUPURA.			
136	0·710	..	16·96	0·042	..
137	0·290	..	7·52	0·039	..
138	0·205	2·26	..	..	..
139	0·165	3·98	..	..	..
140	0·888	5·72	..	..	..
141	0·329	3·05	..	..	..
142	0·825	6·11	..	..	..
143	1·142	2·18	..	..	..
144	0·196	2·81	..	..	..
145	0·791	5·74	..	..	..
146	0·330	6·30	..	..	..
147	0·536	3·41	..	..	..
148	0·727	5·43	..	..	..
149	0·899	7·36	..	..	..
		GUJRAT.			
150	0·760	..	14·08	0·054	..
151	0·372	..	4·64	0·080	..
152	0·702	..	13·44	0·052	..
		MONTGOMERY.			
153	..	..	17·50	..	..
156	0·780	..	10·88	0·072	..

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SURFACE SOILS—*contd.*			
		MONTGOMERY—*contd*			
157	0·950	..	..	..	..
158	0·810	5·20	12·40	0·065	0·41
159	0·720	5·27	11·40	0·063	0·40
160	0·630	4·54	11·44	0·055	0·40
161	0·760	4·47	11·54	0·066	0·39
162	0·780	4·97	12·43	0·063	0·40
163	0·900	4·83	11·72	0·077	0·41
165	1·040	5·55	14·59	0·071	0·38
167	0·770	4·66	12·78	0·060	0·36
169	0·840	4·29	11·65	0·072	0·37
171	0·990	5·21	18·72	0·053	0·29
		LYALLPUR.			
173	0·827	..	10·95	0·075	..
174	1·250	..	..	..	..
175	1·300	..	..	..	..
176	1·030	..	..	..	..
177	1·190	..	..	..	..
178	1·200	..	..	..	..
179	0·960	..	..	..	..
180	0·780	..	..	..	..
181	0·760	..	..	..	..

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
			SURFACE SOILS—*contd.*		
			LYALLPUR—*contd.*		
182	0·500	5·28	15·60	0·032	0·34
184	0·550	4·40	10·14	0·054	0·43
			SHAHPUR.		
186	0·956	..	7·04	0·014	..
187	0·743	..	13·92	0·053	..
188	..	..	12·64	..	..
			SHAHPUR (MONA).		
197	0·884	10·19	21·12	0·042	0·51
199	0·549	8·53	28·64	0·020	0·30
201	0·397	4·68	10·72	0·037	0·44
203	1·079	7·96	23·69	0·046	0·34
205	1·020	8·25	22·08	0·046	0·37
			SHAHPUR (SARGODHA).		
206	0·693	6·86	15·84	0·044	0·43
208	0·724	7·24	20·96	0·035	0·35
210	0·547	5·13	8·00	0·068	0·64
212	0·689	6·10	16·00	0·043	0·38
			JHANG.		
214	0·847	..	5·58	0·015	..
215	0·837	..	4·90	0·017	..

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SURFACE SOILS—*contd.*			
		MULTAN.			
228	0·675	5·99	..	..	..
229	0·808	6·14	..	..	..
		MUZAFFARGARH.			
230	0·861	..	20·32	0·042	..
231	0·822	..	13·28	0·062	..
		DERA GHAZI KHAN.			
232	0·687	..	9·28	0·074	..
233	0·802	..	16·48	0·049	..
		SUB-SOILS.			
		GURDASPUR.			
49	0·57	5·33	21·36	0·026	0·25
51	0·53	4·35	19·01	0·028	0·23
53	0·44	3·77	11·70	0·038	0·32
		RAWALPINDI.			
55	0·59	5·38	14·08	0·042	0·38
57	0·51	3·48	22·24	0·023	0·16
59	0·47	3·92	6·72	0·070	0·58

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH - CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SUB SOILS—*contd.*			
		ATTOCK (2ND FOOT).			
61	0·88	8·86	23·00	0·038	0·38
64	0·46	5·84	32·40	0·014	0·18
67	0·41	5·68	20·98	0·019	0·27
70	0·62	9·37	21·12	0·029	0·44
73	0·54	7·83	17·63	0·031	0·44
76	0·72	8·96	25·80	0·028	0·35
79	0·49	9·42	19·20	0·025	0·49
82	0·80	7·06	19·04	0·042	0·37
85	·84	7·16	17·86	0·047	0·40
88	0·81	8·65	16·00	0·050	0·55
		ATTOCK (3RD FOOT).			
62	0·73	6·11	27·25	0·027	0·22
65	0·78	7·89	39·52	0·020	0 20
68	0·40	6·64	19·35	0·021	0·34
71	0·60	7·67	20·56	0·029	0·37
74	0·64	7·67	22·36	0·029	0·34
77	0·52	7·69	25·20	0·021	0·31
80	0·49	7·06	17·62	0·028	0·40
83	0·65	7·22	16·96	0·038	0·43
86	1·06	7·88	19·20	0·055	0·41
89	0·75	8·52	15·00	0·05	0·56

TABLE VI—*contd.*

The Punjab Soils—contd.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Soil No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SUB-SOILS—*contd.*			
		HISSAR.			
98	0·63	5·96	21·76	0·029	0·27
100	0·59	6·10	21·28	0·028	0·29
102	0·77	8·00	36·64	0·021	0·22
104	0·38	3·29	15·52	0·024	0·21
		KARNAL.			
120	0·65	4·75	16·64	0·039	0·28
122	0·91	7·31	12·96	0·070	0·56
124	0·88	7·31	14·88	0·059	0·49
		FEROZEPUR.			
129	0·79	5·98	13·76	0·057	0·44
131	0·76	5·97	15·52	0·049	0·38
		JULLUNDUR.			
132	0·79	..	6·90	0·011	..
133	1·50	..	28·08	0·053	..
		MONTGOMERY.			
164	0·85	5·19	13·48	0·063	0·38
166	1·05	5·79	15·87	0·066	0·37
168	0·80	4·53	14·72	0·054	0·31

TABLE VI—*concld.*

The Punjab Soils—concld.

POTASH : CLAY, AND ALUMINIA : CLAY RATIOS—*contd.*

(% on air dried soils.)

Serial No.	Potash K_2O	Aluminia Al_2O_3	Clay	Potash : Clay	Aluminia : Clay
		SUB-SOILS—*contd.*			
		MONTGOMERY—*contd.*			
170	0·77	4·74	10·24	·075	0·46
172	1·12	5·54	18·05	0·062	0·31
		LYALLPUR.			
183	·60	5·57	14·40	·042	·39
185	·60	4·30	10·64	·056	·40
		SHAHPUR (MONA).			
198	·956	8·59	25·60	·037	·34
200	·901	8·53	32·32	·028	·26
202	·34	4·10	9·44	·036	·43
204	·90	8·76	23·84	·038	·37
		SHAHPUR (SARGODHA).			
207	·89	6·88	15·36	·058	·45
209	1·06	8·27	26·40	·040	·31
211	·50	5·10	8·48	·059	·60
213	·59	5·63	16·96	·035	·33

Table VII.

The Punjab Soils.

Phosphoric Acid.

Soil No.	Locality	P_2O_5 per cent.	Soil No.	Locality	P_2O_5 per cent
1	Kangra	0·34	26	Gurdaspur	0·62
2	"	0·79	27	"	0·82
3	"	0·39	28	"	0·45
4	"	0·47	29	"	0·44
5	"	0·34	30	"	0·49
6	"	0·30	31	"	0·41
7	"	0·22	32	"	0·44
8	Amballa	0·16	33	"	0·33
9	"	0·21	34	"	0·12
10	"	0·14	35	"	0·16
11	"	0·11	36	"	0·14
12	"	0·24	37	"	0·07
13	"	0·18	38	"	0·18
14	"	0·15	39	"	0·10
15	Hoshiarpur	0·46	40	"	0·05
16	"	0·13	41	"	0·06
17	Gurdaspur	0·16	42	"	0·06
18	"	0·18	43	"	0·07
19	"	0·11	44	"	0·18
20	"	0·11	45	"	0·07
21	"	0·06	46	"	0·05
22	"	0·71	48	"	0·10
23	"	0·65	50	"	0·08
24	"	0·56	52	"	0·16
25	"	0·64	54	Rawalpindi	0·20

TABLE VII—*contd.*

The Punjab Soils—contd.

PHOSPHORIC ACID—*contd.*

Soil No.	Locality	P_2O_5 per cent.	Soil No.	Locality	P_2O_5 per cent.
55	Rawalpindi	0·21	107	Hissar	0·15
58	„	0·16	108	„	0·13
60	Attock	0·17	109	„	0·13
63	„	0·10	110	Karnal	0·36
66	„	0·17	111	„	0·39
69	„	0·10	119	„	0·13
72	„	0·10	121	„	0·12
75	„	0·37	123	„	0·14
78	„	0·26	125	„	0·13
81	„	0·20	126	Ferozepur . . .	0·24
84	„	0·12	127	„	0·29
87	„	0·04	128	„	0·21
90	„	0·02	130	„	0·23
91	Hissar	0·11	132	Jullundur . . .	0·21
92	„	0·11	133	„	0·16
93	„	0·16	134	Lahore . . .	0·13
94	„	0·14	135	„	0·10
95	„	0·14	136	Sheikhupura . .	0·13
96	„	0·12	137	„	0·11
97	„	0·32	138	„	0·16
99	„	0·24	139	„	0·15
101	„	0·19	140	„	0·09
103	„	0·22	141	„	0·13
105	„	0·15	142	„	0·20
106	„	0·32	143	„	0·25

TABLE VII—*contd.*

The Punj. Soils—contd.

PHOSPHORIC ACID—*contd.*

Soil No.	Locality	P_2O_5 per cent.	Soil No.	Locality	P_2O_5 per cent.
144	Sheikhupura . .	0·14	177	Lyallpur . . .	0·20
145	"	0·08	178	"	0·18
146	"	0·12	179	"	0·14
147	"	0·12	180	"	0·14
148	"	0·20	181	"	0·14
149	"	0·15	182	"	0·23
150	Gujrat . . .	0·23	184	"	0·22
151	"	0·16	186	Shahpur . . .	0·22
152	"	0·29	187	"	1·60 ?
156	Montgomery . .	0·15	188	"	0·28
157	"	0·29	197	Shahpur Mona . .	0·15
158	"	0·19	199	" " . .	0·17
159	"	0·21	201	" " . .	0·15
160	"	0·23	203	" " . .	0·23
161	"	0·21	205	" " . .	0·24
162	"	0·19	206	Shahpur Sargodha .	0·23
163	"	0·21	208	" " .	0·26
165	"	0·20	210	" " .	0·18
167	"	0·21	212	" " .	0·16
169	"	0·18	214	Jhang	0·64
171	"	0·21	215	"	0·63
173	Lyallpur . . .	0·35	216	Multan . . .	0·53
174	"	0·21	217	"	0·24
175	"	0·16	228	"	0·17
176	"	0·15	229	"	0·16

TABLE VII—*contd.*

The Punjab Soils—contd.

PHOSPHORIC ACID—*contd.*

Soil No.	Locality	P_2O_5 per cent.	Soil No.	Locality	P_2O_5 per cent.
230	Muzaffargarh . .	0·20	232	Dera Ghazi Khan . .	0·67
231	,, . .	0·22	233	,, . .	1·36 ?

TABLE VIII.

The Punjab Soils.

IRON AND ALUMINIUM.

Soil No.	Iron	Aluminium	Soil No.	Iron	Aluminium
SURFACE SOILS.					
AMBALLA.			ATTOCK.		
10	3·21	2·50	60	4·32	7·13
11	3·29	2·44	63	4·21	6·31
12	3·68	3·07	66	4·93	6·75
13	2·34	3·57	69	5·99	7·73
14	2·95	3·73	72	4·72	6·01
			75	4·08	5·67
GURDASPUR.			78	3·58	9·29
48	4·24	4·68	81	5·58	7·31
50	3·16	3·47	84	4·86	6·98
52	3·08	3·56	87	4·96	7·86
			90	5·94	8·80
RAWALPINDI.					
54	5·09	5·92	HISSAR.		
56	3·66	5·91	97	3·28	4·58
58	4·52	5·86	99	4·10	6·74

TABLE VIII—*contd.*

The Punjab Soils—contd.

IRON AND ALUMINIUM—*contd.*

Soil No.	Iron	Aluminium	Soil No.	Iron	Aluminium
		SURFACE SOILS—*contd.*			
	HISSAR—*contd.*			SHEIKHUPURA—*contd.*	
101	4·96	6·99	144	1·28	2·81
105	4·04	4·71	145	3·26	5·74
106	3·84	5·88	146	4·10	6·30
107	4·08	5·50	147	1·94	3·41
108	3·80	5·59	148	4·42	5·43
109	3·68	4·85	149	3·82	7·36
	KARNAL.				
119	4·08	4·86		MONTGOMERY.	
121	4·08	5·02	158	3·60	5·20
123	3·47	6·57	159	3·20	5·27
125	3·04	3·98	160	4·00	4·54
	FEROZEPUR.		161	3·76	4·47
			162	3·96	4·97
128	4·24	5·83	163	4·20	4·83
130	4·12	5·49	165	4·40	5·55
			167	4·12	4·66
	SHEIKHUPURA.		169	4·04	4·29
138	1·98	2·26	171	4·60	5·21
139	1·78	3·98			
140	3·26	5·72			
141	1·86	3·05		LYALLPUR.	
142	4·33	6·11	182	2·38	5·28
143	4·44	2·18	184	2·63	4·40

TABLE VIII—*contd.*

The Punjab Soils—contd.

IRON AND ALUMINIUM—*contd.*

Soil No.	Iron	Aluminium	Soil No.	Iron	Aluminium
		SURFACE SOILS—*concld.*			
	SHAHPUR (MONA).			SHAHPUR (SARGODHA)—*contd.*	
197	2·64	10·19	210	3·76	5·13
199	4·72	8·53	212	5·05	6·10
201	3·44	4·68			
203	5·38	7·96			
205	3·89	8·25			
	SHAHPUR (SARGODHA).			MULTAN.	
206	4·44	6·86	228	4·46	5·99
208	4·85	7·24	229	4·92	6·14
		SUB-SOILS.			
	GURDASPUR.			ATTOCK (II ft.)—*contd.*	
49	4·60	5·33	67	4·32	5·68
51	3·53	4·35	70	6·00	9·37
53	3·38	3·77	73	5·20	7·83
	RAWALPINDI.		76	3·36	8·96
55	4·93	5·38	79	3·20	9·42
57	3·40	3·48	82	5·20	7·06
59	4·48	3·92	85	4·92	7·16
			88	5·71	8·65
	ATTOCK (II ft.).			ATTOCK (III FT.).	
61	4·50	8·86	62	4·31	6·11
64	4·30	5·84	65	4·22	7·89

TABLE VIII—*contd.*

The Punjab Soils—contd.

IRON AND ALUMINIUM—*contd.*

Soil No.	Iron	Aluminium	Soil No.	Iron	Aluminium
		SUB-SOILS—*contd.*			
	ATTOCK (III FT.)—*contd.*			MONTGOMERY.	
68	5·60	6·64	164	4·28	5·19
71	5·48	7·67	166	4·44	5·79
74	6·08	7·67	168	4·40	4·53
77	3·41	7·69	170	4·10	4·74
80	3·69	7·06	172	4·64	5·54
83	5·36	7·22			
86	5·40	7·88		LYALLPUR.	
89	5·88	8·52	183	2·52	2·27
	HISSAR.		185	5·57	4·30
98	3·56	5·96			
100	4·20	6·10		SHAHPUR (MONA).	
102	5·12	8·00	198	5·68	8·59
104	5·60	3·29	200	5·72	8·53
			202	3·64	4·10
	KARNAL.		204	5·77	8·76
120	4·20	4·75			
122	3·42	7·31			
124	3·47	7·31		SHAHPUR (SARGODHA).	
			207	4·90	6·88
	FEROZEPUR.		209	5·72	8·27
129	4·32	5·98	211	3·79	5·10
131	4·69	5·97	213	4·88	5·63

Table IX.

The Punjab Soils.

Metallic bases in relation to Silica and Aluminia.

(% on air dried soil.)

Soil No.	Silica	Aluminia	Bases (CaO, MgO, Na_2O, K_2O)	Silica :	Aluminia :	Bases
			SURFACE SOILS.			
			Ambala.			
10	90·33	2·50	2·73	36·10	1	1·1
11	90·88	2·44	2·81	37·24	1	1·2
12	87·52	3·07	2·52	28·51	1	0·8
13	90·63	3·57	2·65	25·38	1	0·7
14	89·43	3·73	2·83	23·98	1	0·7
			Average .	30·24	1	·9
			Gurdaspur.			
48	88·32	4·68	2·44	18·87	1	0·5
50	88·31	3·47	2·89	25·45	1	0·8
52	91·95	3·56	3·12	25·83	1	0·9
			Average .	23·38	1	·7
			Rawalpindi.			
54	67·61	5·95	14·29	11·37	1	2·4
56	64·74	5·91	14·33	10·95	1	2·4
58	72·80	5·86	1·00	13·00	1	2·0
			Average .	11·77	1	2·3

TABLE IX—*contd.*

The Punjab Soils—contd.

METALLIC BASES IN RELATION TO SILICA AND ALUMINIA—*contd.*

(% on air dried soil.)

Soil No.	Silica	Aluminia	Bases (CaO, MgO, Na_2O, K_2O)	Silica :	Aluminia :	Bases
			SURFACE SOILS—*contd.*			
			HISSAR.			
97	85·02	4·58	4·31	18·56	1	0·9
99	88·57	6·74	4·81	12·70	1	0·7
101	84·83	6·99	3·85	12·13	1	0·56
105	85·33	4·71	2·72	18·75	1	0·6
106	85·06	5·88	3·03	14·47	1	0·5
107	84·97	5·50	2·80	15·45	1	0·5
108	86·30	5·59	2·08	15·44	1	0·3
109	87·43	4·85	2·02	18·03	1	0·4
			AVERAGE .	15·70	1	·56
			KARNAL.			
119	87·17	4·86	3·17	17·94	1	·66
121	86·63	5·02	2·94	17·26	1	·58
123	83·92	6·57	3·55	12·77	1	·50
125	88·79	3·98	2·31	22·31	1	·6
			AVERAGE .	17·57	1	·58
			FEROZEPUR.			
128	76·76	5·83	7·84	13·17	1	1·3
130	77·22	5·49	8·07	14·06	1	1·5
			AVERAGE .	13·61	1	1·4

TABLE IX—*contd.*

The Punjab Soils—contd.

METALLIC BASES IN RELATION TO SILICA AND ALUMINIA—*contd.*

(% on air dried soil.)

Soil No.	Silica	Aluminia	Bases (CaO MgO, Na_2O, K_2O)	Silica :	Aluminia :	Bases
			SURFACE SOILS—*contd.*			
			MONTGOMERY.			
158	81·86	5·2	8·14	15·74	1	1·5
159	83·56	5·27	7·92	15·85	1	1·5
160	86·38	4·54	6·35	19·02	1	1·4
161	82·23	4·47	8·90	18·40	1	2·0
162	84·03	4·97	7·92	16·91	1	1·6
163	81·31	4·83	5·95	16·83	1	1·2
165	79·16	5·55	6·40	14·25	1	1·1
167	82·91	4·66	5·80	17·79	1	1·2
169	81·19	4·29	7·04	18·93	1	1·6
171	78·05	5·21	7·37	14·98	1	1·4
			AVERAGE .	16·87	1	1·45
			LYALLPUR.			
182	81·84	5·28	6·68	15·50	1	1·2
184	88·10	4·40	3·36	22·02	1	0·7
			AVERAGE .	18·76	1	·95

TABLE IX—*contd.*

The Punjab Soils—contd.

METALLIC BASES IN RELATION TO SILICA AND ALUMINIA—*contd.*

(% on air dried soil.)

Soil No.	Silica	Aluminia	Bases (CaO, MgO, Na_2O, K_2O)	Silica :	Aluminia :	Bases
			SURFACE SOILS—*concld.*			
			SHAHPUR.			
197	78·61	10·19	5·53	7·71	1	·54
199	75·92	8·53	3·09	8·90	1	·36
201	79·64	4·68	8·19	17·01	1	1·75
203	78·03	7·96	4·64	9·80	1	·58
205	79·30	8·25	5·48	9·61	1	·66
207	76·90	6·86	5·92	11·21	1	·86
209	81·52	8·27	6·21	9·86	1	·75
211	70·84	5·10	10·27	13·89	1	2·01
213	77·44	5·63	5·25	13·75	1	·93
			AVERAGE ..	11·30	1	·94
			SUB-SOILS.			
			GURDASPUR.			
49	87·14	5·33	2·33	16·35	1	0·4
51	88·54	3·47	2·89	20·36	1	0·7
53	90·03	3·77	1·73	23·88	1	0·5
			AVERAGE .	20·20	1	·53

TABLE IX—*contd.*

The Punjab Soils—contd.

METALLIC BASES IN RELATION TO SILICA AND ALUMINIA—*contd.*

(% on air dried soil.)

Soil No.	Silica	Aluminia	Bases (CaO, MgO, Na_2O, K_2O)	Silica :	Aluminia :	Bases
			SUB-SOILS—*contd.*			
			RAWALPINDI.			
55	65·76	5·38	12·70	12·22	1	2·36
57	63·39	3·48	14·69	18·22	1	4·2
59	71·68	3·92	11·78	18·28	1	3·0
			AVERAGE .	16·57	1	3·19
			HISSAR.			
98	82·42	5·96	4·65	13·83	1	0·9
100	84·73	6·10	5·16	13·89	1	0·8
102	84·53	8·00	3·56	10·57	1	0·44
104	86·34	3·29	2·57	26·24	1	0·80
			AVERAGE .	16·13	1	·72
			KARNAL.			
120	85·71	4·75	2·98	18·04	1	0·60
122	81·78	7·31	3·27	11·19	1	0·40
124	88·79	3·98	2·31	11·41	1	·40
			AVERAGE .	13·55	1	·50
			FEROZEPUR.			
129	75·07	5·98	8·40	12·55	1	1·4
131	74·31	5·97	8·76	12·41	1	1·5
			AVERAGE .	12·49	1	1·5

TABLE IX—*contd.*

The Punjab Soils—contd.

METALLIC BASES IN RELATION TO SILICA AND ALUMINIA—*contd.*

(% on air dried soils.)

Soil No.	Silica	Aluminia	Bases (CaO, MgO, Na_2O, K_2O)	Silica :	Aluminia :	Bases
			SUB-SOILS—*concld.*			
			MONTGOMERY.			
164	81·34	5·19	6·48	15·67	1	1·2
166	76·09	5·79	7·94	13·14	1	1·3
168	81·11	4·53	6·80	17·91	1	1·5
170	79·26	4·74	8·40	16·72	1	1·8
172	77·56	5·54	7·99	14·00	1	1·4
			AVERAGE .	15·49	1	1·4
			LYALLPUR.			
183	78·49	5·57	6·99	14·09	1	1·2
185	86·79	4·30	4·09	20·18	1	0·9
			AVERAGE .	17·14	1	1·1
			SHAHPUR.			
198	62·29	8·59	4·98	7·25	1	·58
200	75·21	8·53	4·52	8·82	1	·53
202	75·39	4·10	6·55	18·39	1	1·60
204	76·51	8·76	4·25	8·73	1	·48
206	77·49	6·86	6·38	12·15	1	·93
208	76·05	7·24	12·79	10·51	1	1·77
210	78·95	5·13	7·44	15·39	1	1·45
212	68·25	6·10	12·39	11·19	1	2·03
			AVERAGE .	11·55	1	1·17

TABLE X.

The Punjab Soils.

ANALYSES OF WHEAT SOILS.

LOCALITY	AMBALLA		HOSHIAR-PUR	GURDAS-PUR	RAWALPINDI		HISSAR		
DESCRIPTION	S. L. 1	L. 1	S. L. 2	L. 4	L. 1	C. L. 2	C. L. 1	S. L. 2	L. 3
Number	8	10	15	20	54	56	93	95	106
Mechanical.									
Fine Gravel	*Nil*	*Nil*	0·68	0·71	0·53	0·14	0·43	0·12	0·22
Coarse sand	·89	2·96	21·02	7·46	2·37	1·02	·60	4·46	2·02
Fine sand	71·79	50·82	41·46	31·64	26·86	19·38	62·38	59·12	53·50
Silt	13·07	24·63	14·40	23·40	32·15	25·96	10·11	11·59	16·20
Fine silt	7·36	11·36	10·88	20·48	17·92	24·80	9·28	8·32	14·45
Clay	4·89	6·72	8·32	11·20	13·92	22·08	12·80	11·20	13·28
Chemical.									
Potash as K_2O	0·41	0·22	0·60	0·83	0·70	0·50	0·65	0·71	1·01
Phosphoric acid P_2O_5	0·16	0·14	0·46	0·11	0·20	0·21	0·16	0·14	0·32
Lime as CaO	1·19	0·93	2·51	0·84	11·44	11·20	2·04	1·05	1·23
Magnesia as MgO	0·85	1·15	1·1	1·63	1·75	2·17	1·07	1·37	0·69
Iron and Aluminium (Fe_2O_3 + Al_2O_3).	6·91	3·21 *plus* 2·50	6·71	10·70	5·09 *plus* 5·92	3·66 *plus* 5·91	8·42	8·73	3·84 *plus* 5·88
Potash (Available)	..	..	..	..	..	..	..	..	..
Phosphoric (Available)	..	..	..	..	..	..	..	..	..
NITROGEN (o/o on air dried soil)	0·02	0·06	0·05	0·047	0·07	0·04	0·04	0·04	0·05

TABLE X—*contd.*

The Punjab Soils—contd.

ANALYSES OF WHEAT SOILS—*contd.*

LOCALITY	KARNAL			FEROZEPUR		JULLUNDUR	LAHORE	SHEIKHUPURA	
DESCRIPTION	C. L. 1	L. 4	L. 3	L. 5	L. 4	C	L. 4	L. 3	L. 3
Number	110	121	125	126	128	133	135	136	137
Mechanical.									
Fine Gravel	*Nil*	0·05	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*	0·39	0·52
Coarse sand	9·84	1·74	21·0	9·90	3·82	1·82	2·01	15·74	23·20
Fine sand	40·32	47·29	36·62	26·84	40·47	6·22	45·63	36·73	36·24
Silt	15·38	18·67	25·18	26·67	20·30	17·56	22·88	16·18	17·53
Fine silt	17·92	16·96	7·52	17·75	15·76	38·28	12·16	9·92	8·00
Clay	14·72	16·96	7·52	14·56	13·60	38·08	15·04	16·96	7·52
Chemical.									
Potash as K_2O	0·87	0·67	0·64	1·09	0·78	1·46	0·93	0·71	0·29
Phosphoric acid P_2O_5	0·36	0·12	0·13	0·24	0·21	0·16	0·10	0·13	0·11
Lime as CaO	2·17	0·43	1·09	4·13	4·71	..	1·24	1·33	3·25
Magnesia as MgO	1·29	1·34	0·46	2·65	1·94	..	1·19	0·93	1·94
Iron and Aluminium (Fe_2O_3 + Al_2O_3.)	8·74	4·08 *plus* 5·02	3·04 *plus* 3·98	11·12	4·24 *plus* 5·83	..	11·52	11·02	5·74
Potash (Available)	..	..	..	..	..	..	..	..	..
Phosphoric (Available)	..	..	..	..	..	..	..	..	..
NITROGEN (o/o on air dried soil)	0·05	0·07	0·04	0·10	0·08	0·16	0·04	0·04	0·04

TABLE X—*conc'd.*

The Punjab Soils—concld.

ANALYSES OF WHEAT SOILS—*concld.*

LOCALITY	MONTGOMERY	LYALLPUR	SHAHPUR	JHANG	MUZAFFARGARH	DERA GHAZI KHAN	MULTAN
DESCRIPTION	L. 3	L. 3	S. L. 2	St.	C.	S. L. 2	St.
Number	162	173	186	214	231	233	216
Mechanical.							
Fine Gravel	1·00	0·34	0·06	*Nil*	*Nil*	*Nil*	*Nil*
Coarse sand	2·54	8·24	17·63	9·44	4·08	40·82	7·36
Fine sand	46·43	41·32	45·07	12·00	41·47	18·72	14·92
Silt	20·63	18·63	15·63	20·80	22·02	9·93	22·58
Fine silt	13·85	18·70	8·00	48·73	12·32	10·24	47·69
Clay	12·43	10·95	7·04	5·58	13·28	16·48	3·78
Chemical.							
Potash as K_2O	0·78	0·83	0·96	0·85	0·82	0·80	0·85
Phosphoric acid P_2O_5	0·19	0·35	0·22	0·64	0·22	1·36	0·64
Lime as CaO	5·05	6·28	3·42	4·40	6·02	6·03	4·40
Magnesia as MgO	1·94	0·89	1·86	1·60	1·99	1·73	1·60
Iron and Aluminium ($Fe_2O_3 + Al_2O_3$)	3·96 *plus* 4·97	9·99	9·90	8·45	10·74	8·30	8·45
Potash (Available)	..	..	..	..	..	..	..
Phosphoric (Available)	..	..	..	..	..	..	..
NITROGEN (% on air dried soil)	0·05	0·04	0·03	0·05	0·05	0·04	0·05

TABLE XI.

The Punjab Soils.

ANALYSES OF COTTON SOILS.

LOCALITY	GURDASPUR	HISSAR			MONTGOMERY	LYALLPUR	SHAHPUR	JHANG	MULTAN	LAHORE
DESCRIPTION	L. 3	S. L. 2	C. L. 1	L. 3	L. 3	L. 3	L. 3	St.	H. St. L.	
Number	30	92	93	94	162	173	187	214	217	135
Mechanical.										
Fine Gravel	0·41	*Nil*	0·43	0·08	1·00	0·34	*Nil*	*Nil*	0·12	*Nil*
Coarse sand	23·87	1·30	0·60	0·46	2·54	8·24	10·89	9·44	1·10	2·01
Fine sand	32·30	65·55	62·38	59·12	46·43	41·32	44·32	12·00	14·22	45·63
Silt	17·92	9·29	10·11	11·59	20·63	18·63	13·50	20·80	31·79	22·88
Fine silt	12·99	9·12	9·28	8·32	13·85	18·70	14·24	48·73	30·40	12·16
Clay	12·48	13·44	12·80	11·20	12·43	10·95	13·92	5·58	14·72	15·04
Chemical.										
Potash as K_2O	0·29	0·50	0·65	0·72	0·78	0·83	0·74	0·85	0·72	0·93
Phosphoric acid as P_2O_5.	0·49	0·11	0·16	0·14	0·19	0·35	1·61	0·64	0·24	0·10
Lime as CaO	0·27	0·99	2·04	0·92	5·05	6·28	3·45	4·40	3·06	1·24
Magnesia as MgO	0·82	0·86	1·07	0·87	1·94	0·89	1·29	1·60	1·23	1·29
Iron and Aluminium ($Fe_2O_3 + Al_2O_3$.)	6·87	8·12	8·42	8·75	3·96 *plus* 4·97	9·99	8·02	8·45	10·73	11·52
Potash (Available)	0·03	..	..	..	..	..	..	..	..	..
Phosphoric (Available)	0·11	..	..	..	..	..	..	..	..	..
NITROGEN (o/o on air dried soil).	0·052	0·04	0·04	0·05	0·05	0·04	0·037	0·05	0·06	0·04

TABLE XII.

The Punjab Soils.

ANALYSES OF SUGARCANE SOILS.

LOCALITY	HOSHIARPUR	GURDASPUR				HISSAR	KARNAL	LAHORE	SHEIKHUPURA	GUJRAT	MONTGOMERY	SHAHPUR
DESCRIPTION	S. L. 1	S. L. 2	L. 3	L. 5	L. 1	S. L. 2	L. 5	L. 5	L. 3	L. 5	L. 3	L. 3
Number	16	19	28	29	33	103	111	135	136	150	162	188
Mechanical.												
Fine Gravel	·03	..	1·14	0·25	0·11	0·07	*Nil*	*Nil*	0·39	*Nil*	1·00	*Nil*
Coarse sand	36·60	35·99	25·96	23·00	23·70	·62	2·38	2·01	15·74	14·79	2·54	13·91
Fine sand	38·54	30·22	28·10	22·91	27·23	60·77	46·05	45·63	36·73	26·83	46·43	39·39
Silt	10·38	11·52	16·10	20·01	25·44	16·85	18·17	22·86	16·18	25·15	20·63	17·86
Fine silt	6·40	10·24	12·71	17·93	12·94	9·28	18·24	12·16	9·92	12·80	13·85	11·20
Clay	7·04	9·28	10·23	15·60	7·36	14·24	16·16	15·04	16·96	14·08	12·43	12·64
Chemical.												
Potash as K_2O	0·42	0·74	0·35	0·30	0·32	0·57	0·88	0·93	0·71	0·76	0·78	..
Phosphoric acid P_2O_5	0·13	0·11	0·45	0·44	0·33	0·22	0·39	0·10	0·13	0·23	0·19	0·28
Lime as CaO	0·63	0·37	0·90	0·28	0·27	1·16	1·28	1·24	1·33	1·23	5·05	3·23
Magnesia as MgO	0·85	1·40	1·03	0·97	0·79	0·53	1·55	1·19	·93	1·60	1·94	1·71
Iron and Aluminium ($Fe_2O_3 + Al_2O_3$.)	5·84	8·71	8·08	9·01	8·07	7·84+ 1·36	8·82	11·52	11·02	10·72	3·97+ 4·97	8·69
Potash (Avl.)	..	..	0·05	0·03	0·02	..	..	..	..	..	..	..
Phosphoric (Avl.)	..	..	0·15	0·08	0·04	..	..	..	..	..	..	..
Nitrogen (o/o on air dried soil).	0·06	0·03	0·06	0·06	0·05	0·04	0·05	0·04	0·04	0·07	0·05	0·04

TABLE XIII.

The Punjab Soils.

ANALYSES OF RICE SOILS.

LOCALITY	AMBALLA	GURDASPUR		HISSAR		JULLUNDUR	GUJRAT	MUZAFFARGARH
DESCRIPTION	H. St. L.	L1	St.	Cl.	C. L. 2	C. L.	L5	C. 12
Number	9	17	18	96	101	133	152	230
Mechanical.								
Fine Gravel	*Nil*	*Nil*	*Nil*	0·26	*Nil*	*Nil*	*Nil*	*Nil*
Coarse sand	·89	14·88	6·08	0·12	1·48	1·82	8·61	4·08
Fine sand	71·79	31·84	15·84	36·40	33·91	6·22	29·64	41·47
Silt	13·07	23·47	28·05	9·75	17·24	17·56	26·19	22·02
Fine silt	7·36	23·25	40·39	14·88	19·36	36·28	17·92	12·32
Clay	4·80	4·09	4·62	33·44	26·08	28·08	13·44	13·28
Chemical.								
Potash as K_2O.	0·41	0·69	0·64	1·30	0·74	1·46	0·70	0·82
Phosphoric acid P_2O_5	0·16	0·16	0·18	0·12	0·19	0·16	0·29	0·22
Lime as CaO	1·19	0·49	0·52	0·89	1·37	..	1·21	6·02
Magnesia as MgO.	·85	2·25	1·95	0·62	1·49	..	1·02	1·99
Iron and Aluminium (Fe_2O_3 Al_2O_3)	6·91	11·92	9·81	15·64	4·96+ 6·99	..	10·24	10·74
Potash (Avl.)	..	..	..	..	..	..	..	..
Phosphoric (Avl.)	..	..	..	..	..	..	..	..
Nitrogen	0·02	0·08	0·06	0·05	0·06	0·16	0·08	0·05

TABLE No. XIV.

The Punjab Soils.

ANALYSES OF THE WATER EXTRACT OF ALKALI SOILS.

Per cent on air dry fine earth..

No.	Locality and Description of sample	Total solids	Chlorides as NaCl	Carbonates as Na_2 Co_3	Bicarbonates as Na H Co_3	Sulphates as Na_2 So_4
1	Narwala Reh Farm, Lyallpur . .	2·49	0·234	*Nil*	*Nil*	*Nil*
2	Pinjripur, District Montgomery . .	1·412	0·083	*Nil*	0·068	1·10
3	Bara Farm, Montgomery . . .	0·852	*Nil*	0·070	0·103	*Nil*
4	Alkali land Mianchannu, District Multan	1·46	0·702	0·064	0·084	0·523
5	Alkali land Muzaffarabad, District Multan	1·28	*Nil*	0·237	0·256	*Nil*
6	Alkali land Tehsil Pind Dadan Khan, District Jhelum.	5·82	2·41	Trace.	0·007	*Nil*
7	Alkali land Khushab, District Shahpur .	4·35	3·18	*Nil*	0·006	*Nil*
8	Kallar lands, District Gujranwala . .	0·47	0·009	0·06	0·206	0·187
9	Alkali land Sahiwal, District Shahpur .	1·58	0·62	*Nil*	0·437	0·505

Table No. XV.

The Punjab Soils.

Analyses of Bara Soils.

Description	1st 6″	2nd 6″	II ft.	III ft.	IV ft.	V ft.	VI ft.	VII ft.
Mechanical.								
Fine Gravel	*Nil*	0·04	*Nil*	0·25	0·21	0·36	0·30	0·3
Coarse sand	0·46	0·56	0·34	0·30	0·38	0·22	0·22	0·2
Fine sand	39·70	34·73	34·10	29·01	34·10	29·05	21·93	13·6
Silt	22·50	26·99	27·23	31·70	30·49	34·88	37·80	36·1
Fine silt	19·04	16·64	19·04	18·72	20·64	18·24	23·31	29·9
Clay	14·56	8·32	9·92	9·48	10·08	7·68	10·08	11·8
Chemical.								
Potash as K_2O	0·690	0·925	0·755	0·855	..	0·980	1·000	..
Phosphoric acid as P_2O_2	0·197	0·185	0·167	0·161	0·141	0·134	0·123	0·120
Lime as CaO	4·150	4·090	4·880	6·370	5·930	6·160	6·390	4·000
Magnesia as MgO	2·230	2·250	2·270	2·190	2·380	2·460	2·740	3·100
Iron and Aluminium (Fe_2O_3) Al_2O_3)	10·025	10·255	10·390	10·075	9·220	9·955	10·730	10·080
Potash (Avl.)	..	..	..	..	..	..	..	..
Phosphoric (Avl.)	..	..	..	..	..	..	..	..
Nitrogen (o/o on air dried soil)	0·030	0·027	0·027	0·027	0·021	0·008	0·032	0·03

TABLE No. XVI.

The Punjab Soils.

ANALYSES OF NORMAL SOILS OF MONTGOMERY COLONY.

Description	1st 6″	2nd 6″	II foot	III foot	IV foot	V foot	VI foot	VII foot
Mechanical.								
Fine Gravel	0·63	0·30	0·43	0·21	0·02	0·03	0·02	0·04
Coarse sand	0·63	0·53	0·50	0·66	0·43	0·37	0·34	0·16
Fine sand	39·56	30·56	19·10	24·58	22·43	26·04	16·47	8·22
Silt	18·47	23·58	26·83	27·51	36·65	38·55	45·42	51·39
Fine silt	18·88	18·72	26·66	24·0	21·92	17·76	19·76	23·46
Clay	13·12	13·60	14·56	13·12	8·88	6·88	8·16	8·32
Chemical.								
Potash as K_2O	0·730	1·070	0·570	0·630	0·590	0·710	0·725	0·925
Phosphoric acid as P_2O_5	0·164	0·1590	0·1500	0·1410	0·1380	0·1437	0·1535	0·1530
Lime as CaO	3·82	4·15	5·14	5·08	4·38	3·94	3·53	3·68
Magnesia as MgO	3·11	2·17	2·41	2·60	2·67	2·85	2·28	2·17
Iron and Aluminium (Fe_2O_3) Al_2O_3	7·950	9·265	10·350	10·575	10·895	10·320	9·480	9·935
NITROGEN (o/o on air dried soil)	0·0432	0·0399	0·0378	0·0388	0·0360	0·0345	0·0324	0·0312

Table XVII.

The Punjab Soils.

Analyses of Virgin lands (Nili Bar).

LOCALITY	Kabullah		Between Kabullah and Tibi Lal Beg					
Description	1st 6″	2nd 6″	1st 6″	2nd 6″	2nd foot	3rd foot	4th foot	5th foot
Number	1	1	2	2	2	2	2	2
Mechanical.								
Fine Gravel	0·014	*Nil*	0·04	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
Coarse sand	3·10	3·06	11·91	12·12	9·26	7·31	9·04	6·77
Fine sand	48·39	38·10	45·94	39·05	35·67	55·25	74·48	77·35
Silt	22·92	28·28	11·45	17·12	19·00	16·92	7·68	6·92
Fine silt	14·04	17·84	18·56	26·42	21·18	11·04	4·04	3·92
Clay	9·36	9·84	15·92	11·84	13·44	7·20	4·24	4·08
Chemical.								
Potash as K_2O	..	..	..	..	..	..	..	..
Phosphoric acid as P_2O_5	..	..	..	..	..	..	..	..
Lime as CaO	6·229	6·778	5·423	6·918	..	..	..	..
Magnesia as MgO	..	..	..	..	..	..	..	..
Iron and Aluminium (Fe_2O_3)	..	..	..	..	..	..	..	..
Potash (Avl.)	0·032	0·037	0·0302	0·023	..	..	..	..
Phosphoric (Avl.)	0·0023	0·065	0·0676	0·036	..	..	..	..
Matter soluble in water	0·106	0·168	0·152	0·082	..	..	..	..
Nitrogen (o/o on air dried soil)	..	..	..	..	..	..	..	..

TABLE No. XVII—*contd.*

The Punjab Soils—contd.

ANALYSES OF VIRGIN LANDS (NILI BAR)—*contd.*

LOCALITY	Between Kabullah and Tibi Lal Beg						Sadullapur		
Description	1st 6″	2nd 6″	2nd foot	3rd foot	4th foot	5th foot	1st 6″	2nd 6″	2nd foot
Number	3	3	3	3	3	3	4	4	4
Mechanical.									
Fine Gravel	*Nil*	*Nil*	*Nil*	*Nil*	0·024	0·10	*Nil*	*Nil*	*Nil*
Coarse sand	3·87	2·23	1·25	4·73	13·92	22·77	3·87	4·02	3·61
Fine sand	38·49	32·88	43·52	64·40	56·97	58·53	39·86	40·10	40·44
Silt	27·08	28·46	25·20	15·42	15·84	9·16	23·75	21·36	23·33
Fine silt	15·40	21·68	18·64	6·64	6·60	4·08	13·76	14·36	17·20
Clay	12·88	11·60	9·96	4·80	3·92	3·04	16·32	19·68	14·00
Chemical.									
Nitrogen	..	..	..	..	..	..	..	..	..
Potash as K_2O	..	..	..	..	..	..	..	..	..
Phosphoric acid as P_2O_5	..	..	..	..	..	..	..	..	..
Lime as CaO	7·570	8·170	..	..	..	..	2·342	4·278	..
Magnesia as MgO	..	..	..	..	..	..	..	..	..
Iron and Aluminium $(Fe_2O_3)Al_2O_3$	..	..	..	..	..	..	..	..	..
Potash (Avl.)	0·064	0·046	..	..	..	..	0·026	0·052	..
Phosphoric (Avl.)	0·063	0·019	..	..	..	..	0·0717	0·076	..
Matter soluble in water	0·756	0·390	..	..	..	..	0·232	0·196	..

TABLE No. XVII—*contd.*

The Punjab Soils—contd.

ANALYSES OF VIRGIN LANDS (NILI BAR)—*contd.*

LOCALITY	JAMLERA.			MATEWALA.			BAISAKHIWALA.		
DESCRIPTION	1st 6″	2nd 6″	3rd 6″	1st 6″	2nd 6″	3rd 6″	1st 6″	2nd 6″	3rd 6″
Number	5	5	5	6	6	6	7	7	7
Mechanical.									
Fine Gravel	*Nil*	*Nil*	*Nil*	*Nil*	0·10	*Nil*	*Nil*	0·10	*Nil*
Coarse sand	2·15	1·19	2·45	2·07	1·85	1·33	8·96	9·17	3·91
Fine sand	22·18	13·51	13·76	29·33	21·75	15·65	44·20	35·34	25·80
Silt	23·40	21·17	20·45	25·30	26·30	23·63	16·30	18·29	20·75
Fine silt	26·80	29·24	35·84	23·20	30·00	36·44	16·88	20·00	29·20
Clay	23·44	29·60	24·16	15·04	18·72	13·40	10·80	13·68	16·88
Chemical.									
Nitrogen	..	..	..	..	..	..	..	..	..
Potash as K_2O	..	..	..	..	..	..	..	..	..
Phosphoric acid as P_2O_5	..	..	..	..	..	..	..	..	..
Lime as CaO	1·479	4·415	2·769	3·809	4·542	4·542	4·153	4·166	5·186
Magnesia as MgO	..	..	..	..	..	..	..	..	..
Iron and Aluminium (Fe_2O_3) Al_2O_3	..	..	..	..	..	..	..	..	..
Potash (Avl.)	0·041	0·037	0·024	0·022	0·022	0·032	0·017	0·022	0·067
Phosphoric (Avl.)	0·061	0·053	0·054	0·047	0·034	0·007	0·063	0·009	0·056
Matter soluble in water	0·288	0·352	0·240	0·148	0·136	0·112	0·112	0·072	0·144

MGIPC—M—III-1-82—28-2-29—600.

ADULTERATION OF BUTTER AND GHEE, WITH ANIMAL FAT AND VEGETABLE GHEE, AND ITS DETECTION.

By

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Adulteration of ghee,[1] which is an important article of food in India, has been persistently carried out for a long time. Of late it has assumed such considerable proportions as to be a serious menace to public health. As Shroff[2] points out, fats used for adulteration are often obtained from carcases of diseased animals. Mr. D. A. Rao[3] of South India holds the extreme view that adulteration is necessary to make the preparation of ghee on commercial basis economically paying.

Various measures have been adopted and even legislation enacted in some places, but at best they have been only partially successful to put a stop to the practice.

The task of the analyst has been rendered more difficult by the appearance on the market of an article which goes under the name of 'Vegetable Ghee.'

Methods in vogue are either unsatisfactory or so complicated as to be useless for routine examination of numerous samples. Enquiries received from time to time show that a rapid and reliable method for the detection of adulteration of ghee or butter is in demand.

In India butter and ghee are chiefly made from the milk of buffaloes and cows and only very rarely from that of goats and sheep.

The important physical and chemical characteristics of butter fat and ghee, from same source, have been found by Plymen and Aiyer[4] to be the same.

Owing to great variations in the composition of natural butters and ghee which depend on the breed of the animal, season of milking,[5] kind and quantity of food supplied to the animal and also on the idiosyncrasies of the latter, 'it is not possible by merely carrying out the so called *rapid tests* to detect in every case an admixture of foreign fat when the quantity is small.'[6]

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[1] Bolton, E. R., and Revis, C. Some analyses of ghee. *Analyst* (1910), 35, 343-346.
[2] Watt, G. Commercial Products of India, p. 479.
[3] Rao, D. A. Economics of *Ghi* trade. *Madras Dept. Agri. Bull.* No. 79, Appendix D (1921).
[4] Plymen, F. J., and Aiyer, A. R. P. Mutual applicability of the analytical figures for butter and ghee. *Mem. Dept. Agri. Ind., Chem. Ser.*, (1921), Vol. VI, No. 5.
[5] Plymen, F. J., and Aiyer, A. R. P. Variations in some characteristics of the fat of buffalo and cow milk with changes in season. *Mem. Dept. Agri. Ind., Chem. Ser.*, (1921), Vol. VI, No. 4.
[6] Lewkowitsch. Chemical technology and analysis of oils, fats and waxes. 4th Ed., Vol. I, p. 681.

Fats commonly employed as adulterants may be of animal or of vegetable origin or of both.

For vegetable oils and fats, the Phytosteryl acetate test gives a definite indication of their presence, but uncertainty remains when animal fat is admixed. Generally, the presence of the latter in any quantity is indicated by a lower saponification and Reichert Wollny values which are below 200 and 1 respectively for animal fat, whilst for ghee or butter fat they are 226 to 239[1] and 29 to 42[1] respectively. The above ranges are too wide to detect adulteration with small quantities of animal fat.

Avé Lallement's process is of distinct value in detecting adulteration of animal fat, but it breaks down, according to the author, in the case of overheated or rancid butter; and Trimer[2] takes objection to its use in routine work though he recommends its use as a confirmatory test in cases of suspicious samples.

A number of tests devised to distinguish between fats of different origin have been based upon their variations in solubility in different organic liquids. The best known are those of Valenta[3] and Crismer[4] who determined the critical temperature of dissolution (turbidity temperature) in acetic acid and alcohol respectively. Both the tests are sensitive to slight variations in the moisture content of the solvents.

Seidenberg[5] dissolved fat in a mixture of alcohol and ether aspirated air in the mixture to cause variations in the solvents until turbidity was produced, when the volume of remaining liquid was recorded. The method is open to objection on the ground that water content of alcohol was not taken into account. Atkinson[6] dissolved fat in benzene and added ethylacetoacetate till turbidity was produced. He found the turbidity number for a mixture of 72 per cent. lard and 28 per cent. cocoanut oil to be the same as for pure butter fat. So he evolved a second test using chloroform and ethylacetoacetate which gave the same turbidity number for a mixture of 90 per cent. lard and 10 per cent. cocoanut oil as for butter fat. The latter mixture, however, is readily detected when benzene is used as a solvent.

This method was not tested, as the author admits, with pure butter fat from different sources. The effect of wide variation of temperature on turbidity number was also not studied. Moreover, ethylacetoacetate is a more costly re-agent than ethylacetate which has been used in the method evolved at Pusa.

Crook[7] used 2·5 c.c. of a mixture of carbolic acid and water (10 : 1) for 1 grm. of animal fat when two distinct layers were formed. No distinct layers were ob-

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[1] Ghosh, T. K. Statutory standard for ghee. *Analyst* (1920), 45, 444.

[2] Trimer, S. H. Egyptian Butter and Samna, *Analyst* (1913), 38, 245.

[3] Valenta, E. *Jour. Soc. Chem. Ind.* (1884), 3, 643.

[4] Crismer, L. Critical temperature of dissolution. Application to the analysis of butter. *Abs. Analyst* (1897), 22, 71.

[5] Seidenberg. A method for the detection of foreign fats in butter fat. *J. Ind. Engin. Chem.* (1918), 10, 617-621.

[6] Atkinson, H. J. Miscibility tests in the detection of adulterated butter. *Mc. Gill. Univ. Pub. Ser.* III (*Chem.*), No. 65, (1926).

[7] Crook, W. G. A new method of distinguishing butter fat from some other fats. *Analyst* (1879), 111.

tained at Pusa when buffalo butter fats containing less than 50 per cent. animal fat were tested by that method.

The present enquiry is the outcome of an investigation on the nature of the suspected adulteration in a sample of butter examined at Pusa.

The butter was sticky to the tongue and the fat in it was insoluble in alcohol and difficultly soluble in ether. The sample was marked 'A' butter and analysed and the results compared with those of two other samples, one of which was prepared at Pusa and the other obtained from a reputed firm in India and marked 'B' butter. The results are stated below :—

Composition of butters.

Composition	Pusa buffalo butter	'B' butter	'A' butter	Limits allowed
	Per cent.	Per cent.	Per cent.	
Moisture	18·94	14·71	11·71	Less than 16 per cent.
Fat	80·01	80·82	85·84	More than 80 per cent.
Solids not fat	0·99	2·40	0·74	Less than 2·5 per cent.
Salts	*Nil*	1·67	1·61	0 to 2 per cent.
Ash	0·16	1·89	1·71	

Physical and chemical characteristics of butter fat.

—	Pusa buffalo butter	'B' butter	'A' butter	Limits
Sp. Gr. $\frac{41°C}{41°C}$	0·9137	0·9122	0·9106	0·9100 to 0·9200 (Lewkowitsch, at $\frac{38°C.}{38°C.}$)
Refractive Index, reduced to 25°C (By Abbe's Refractometer).	1·4558	1·4573	1·4578	1·459 to 1·462 (Wollny).
Reichert Wollny value	38·9	31·42	27·8	26 to 42 (Ghosh).
Iodine value	26·41	30·51	32·99	26 to 35 (Hubl).
Saponification value	..	231·7	225·4	226 to 239 (Ghosh).
Stearic acid (By Hehner and Mitchell's method) per cent.	0·33	..	8·43	*Nil* to 1·83

The results show that both 'A' and 'B' butters are within the limits allowed. An abnormal quantity of stearic acid (8·43 per cent.) was, however, found in 'A' butter and this led to the suspicion that it was adulterated with animal fat. With Crook's test, two distinct layers were obtained in 'A' butter fat, while no indication of layers appeared in either Pusa butter or 'B' butter.

On checking Hehner and Mitchell's[1] method with pure stearic acid, it was found to be fairly accurate as the following figures show :—

·046 grm. of pure stearic acid was added to ·466 grm. of buffalo butter fatty acid (insoluble) and ·042 grm. of stearic acid was recovered.

A method was, therefore, sought which is easy of manipulation and also rapid enough for adoption for routine analyses.

The effect of combinations of various organic liquids was then studied on different mixtures of butter and animal fats, to find out one which gives a precipitate with butter fat containing small amounts of animal fat but none in the case of genuine samples at the ordinary laboratory temperature in about half an hour.

Of the solvents experimented with acetic ether (ethylacetate) was found to be suitable, as its boiling point is 77°C and it can be kept dry over calcium chloride. 93 per cent. alcohol was selected as the precipitant as it can readily be obtained by distilling rectified spirit.

By trial a proportion of 3 c.c. of acetic ether to 4 c.c. of 93 per cent. alcohol was found to be suitable, for when 1 grm. of cow or buffalo butter fat is dissolved in 3 c.c. of acetic ether (dry) and 4 c.c. of 93 per cent. alcohol then added to it at 30°C and the mixture kept in a bath at 30°C for half an hour, no precipitate appears. But a precipitate appears under the above conditions when the butter contains 5 per cent. animal fat or over.

It was also observed, that the larger is the amount of animal fat present in the mixture, the quicker is the formation and the more copious is the amount of precipitate obtained by the above test.

The effect of variation of temperature was next studied as follows.

1 grm. each of pure butter fat, butter fat mixed with varying proportions of animal (goat) fat were weighed out in tubes, dissolved in 3 c.c. of acetic ether, the tubes placed in a bath at 40°C and 4 c.c. of 93 per cent. alcohol added to each tube. The contents of the tubes were well mixed and allowed to cool slowly and the temperature observed when precipitates appeared in them. The results are shown below :—

[1] Allen's Commercial Organic Analyses, Vol. II, 4th Ed., p. 393.

Effect of temperature on precipitation by acetic ether—alcohol method.

+ Signifies precipitation.

Tubes	1	2	3	4
Temperature	Buffalo butter fat	9·97 per cent. animal fat in butter fat	15·73 per cent. animal fat in butter fat	24·09 per cent. animal fat in butter fat
38°C . .	..	..	..	..
36 . . .	..	..	..	+
34 . . .	..	..	..	+
33 . . .	..	..	+	+
32 . . .	..	..	+	+
31 . . .	..	+	+	+
30 . . .	..	+	+	+
29 . . .	..	+	+	+
28 . . .	+	+	+	+
27 . . .	+	+	+	+

Only the adulterated samples gave any precipitate at 30°C and this temperature was, therefore, taken as the standard to work to.

Commercial samples of acetic ether often contain moisture, free acid and alcohol as impurities and should, therefore, be carefully purified and dried befcre use. In the present experiments, the following procedure was adopted .

500 c.c. of Merck's acetic ether, sp. gr. 902 to 904 is shaken with 50 c.c. of 5 per cent. sodium carbonate solution, the aqueous layer removed, and the ether washed three times with 30 c.c. of water each time. After separating the wash liquors, the ether is shaken with 50 c.c. of 40 per cent. calcium chloride solution and the etherial layer stored over calcium chloride. It should be filtered through a dry filter paper before using.

The fat precipitated from animal fat by acetic ether—alcohol test was found on examination to give the following characteristics :—

Melting point—50°C (about).

Iodine value—36·94.

Stearic acid—34·81 per cent. in the insoluble fatty acids.

It thus appears to be a mixture of the glycerides of the higher fattyacids and contains a considerable amount of stearic acid.

Quantitative estimation of the precipitate and its relation to the adulteration.

As the precipitates appear in increasing proportions with the increase of adulteration of butter fat with animal fat (Pl. I), an attempt was made to correlate their quantities with the extent of adulteration of butter fat with animal fat.

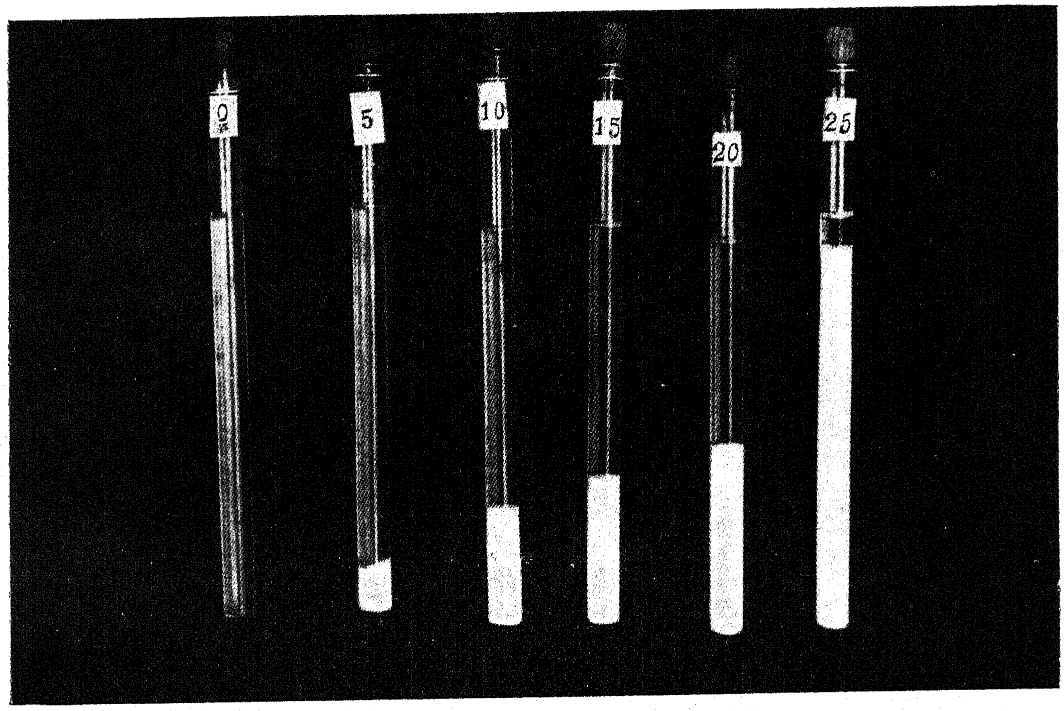
For the above purpose, 1 grm. each of various mixtures of fats were dissolved in 'urine centrifugal tubes' with 3 c.c. of acetic ether and 4 c.c. of 93 per cent. alcohol were added to it at 30°C. The mixture was then shaken and the tubes placed in a bath at 30°C for half an hour. The tubes were next tightly closed with rubber stoppers and centrifuged for 5 minutes at the rate of 1,000 to 1,100 revolutions per minute. The supernatant liquid was then thrown off and the precipitates washed with 4 c.c. of 93 per cent. alcohol by centrifuging as before and the volume of the precipitate read. The supernatant wash liquor was finally removed and the tubes dried in the oven at 100°C for about 2 hours and cooled in a desiccator and weighed. The difference in the weight of the tubes before and after the experiment gives the weight of the precipitate.

The mean results of 5 determinations are shown in the following table.

Determination of the adulteration of buffalo butter fat with animal fat by acetic ether—alcohol method.

Animal fat in the mixture	Volume of precipitate in 'urine tube'	Weight of precipitate grm.
Per cent.		
0	0	*Nil.*
5	0·6	0·04
10	1·0	0·10
15	1·4	0·16
20	1·7	0·21
24·6	2·0	0·23

It will be seen from the above figures that the weight of the precipitate obtained is approximately $\frac{1}{100}$th. grm. of the per cent. of animal fat present in the mixture,



Precipitation of adulterated butter fat by acetic ether—alcohol method. Numbers on the tubes indicate per cent. animal fat present in butter fat.

that is, per cent. adulteration = 100 W, where W = weight of precipitate in grm.

The volume relation may be expressed as follows :—

$$\log\% = \frac{\log V}{\cdot 765} + \cdot 994 = 1\cdot 31 \log V + \cdot 994 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{A}$$

$$\text{or approximately, } \log\% = 1\cdot 31 \log V + 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{B}$$

Calculating on the basis of the above formulae, we get the following figures.

Animal fat in the mixture	Calculated with formula A	Calculated with formula B	Calculated from weight
Per cent.	Per cent.	Per cent.	Per cent.
5 . . .	4·6	5·1	4
10 . . .	9·9	10·0	10
15 . . .	15·3	15·5	16
20 . . .	19·7	20·0	21
24·6 . . .	24·7	24·8	23

The volume relation, therefore, seems to be more approximately correct.

These results are in agreement with those obtained by the cryoscopic determination of the lowering of the freezing points of fats which are detailed below.

Cryoscopy of Fats. The depression of the freezing points of moist benzene through the addition of different quantities of cow's butter fat was determined and a curve plotted. Similarly, a curve for buffalo butter was obtained and these two curves appeared to be practically identical. The coefficients of depression of the freezing points in both the cases were found to vary with concentration of fat in the solvent, but with 18 to 23 per cent. fat in benzene they did not vary more than ·001°C.

The curve for the lowering of the freezing points of animal fat in moist benzene was found to be similar in type to those of cow or buffalo fat, but it diverged from them widely.

The curve obtained for the mixture of animal fat with buffalo butter fat occupied intermediate positions between the curve for buffalo butter fat and that for animal fat ; the curves for the mixtures containing greater proportions of animal fat being nearer to that for pure animal fat.

The mean coefficients of depression of the freezing points of moist benzene for concentrations of 18 to 23 per cent. of different kinds of fats in it are stated below :—

Nature of the fat added to moist benzene.	Mean coefficient of depression of freezing point.
Cow butter fat (mixed milk)	·0832
,, from animal fed with grass only	·0827
,, ,, ,, given concentrated food	·0830
Buffalo butter fat (mixed milk)	·0834
Animal fat	·0549
9·97 per cent. animal fat in buffalo butter fat	·0829
15·73 ,, ,, ,, ,, ...	·0814
24·09 ,, ,, ,, ,, ...	·0774

The lowering of the freezing points of moist benzene containing different quantities of different fats are shown in Charts 1 and 2.

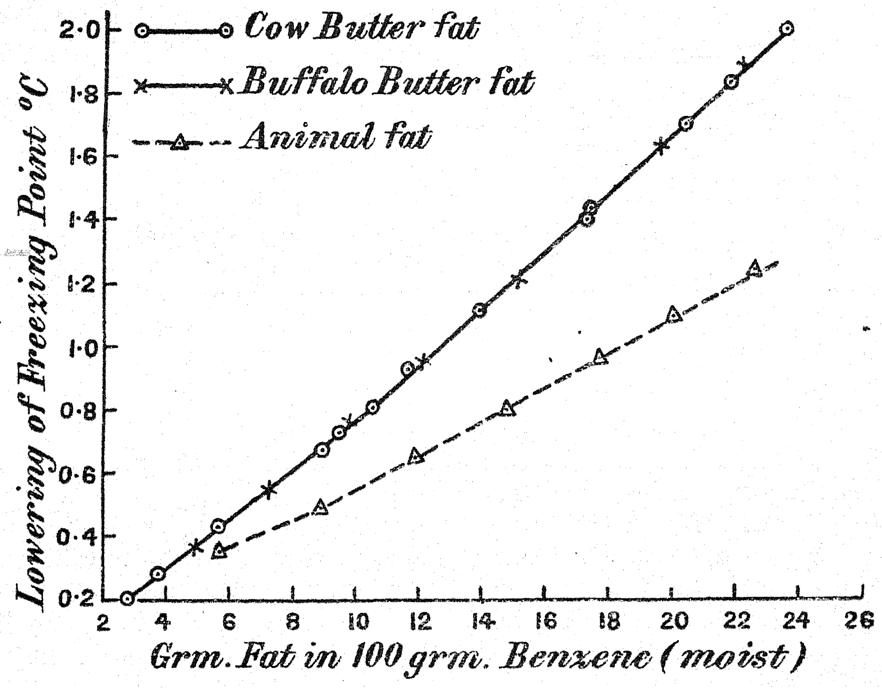


CHART 1.

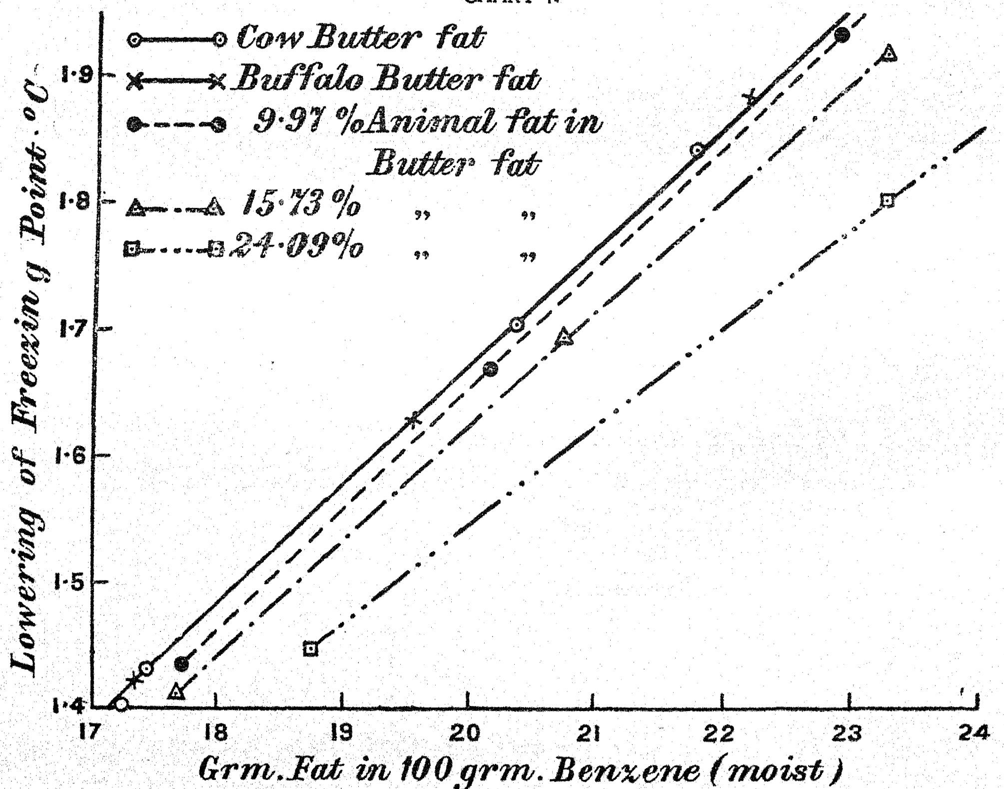


CHART 2.

It will be seen from the above results that it is possible to detect the adulteration of butter fat with 15 per cent. or more of animal fat by this method.

The results are, on the whole, in agreement with those of Pailheret[1] who used dry benzene and consequently got somewhat higher values for the coefficient of lowering of the freezing points between concentrations 18 and 21 per cent. fat in benzene.

General applicability of the acetic ether—alcohol precipitation method.

For the above purpose genuine butter and ghee prepared from cows and buffaloes fed on varying rations were examined. These samples were obtained through the courtesy of the Government Departments of Agriculture of Madras, Bengal, Central Provinces and the State Department of Agriculture, Baroda.

In applying the test, the following precautions were taken :—

(1) Butter was melted and the clear fat, filtered through dry paper, was used for test. In the case of ghee, *the whole of it was thoroughly mixed after melting* and then a representative sample drawn out and filtered before the test was applied. This precaution is necessary as, with an undue proportion of solid (heaviour) portion only of ghee, the test fails.

(2) The reagents were added at 30°C, otherwise, if cold, a precipitate appears immediately. In case this happens, it is advisable to dissolve the precipitate by dipping the tubes in warm water for a second or so and then putting them in the bath at 30°C.

Examination of genuine butter and ghee from different sources.

(*a*) *Butter and ghee from cow.*

No.	Description			3 c.c. acetic ether + 4 c.c. 93 per cent. alcohol + 1 grm. fat, kept at 30°C for ½ hr.
	Nature	Place from	Ration given to animal	
1	Butter fat . .	Dacca Farm .	Grazing only . . .	No precipitate.
2	Ghee . . .	Do. .	Do. . . .	Do.
3	Butter fat . .	Do. .	Green fodder, 2 lb. mustard cake, 3 lb. wheat bran, 2 lb. husk.	Do.
4	Ghee . . .	Do. .	Do. do. .	Do.
5	Do. . . .	Pusa Farm .	Grazing, conc. food (no cotton seed) and green fodder.	Do.
6	Do. . . .	Hosur cattle Farm	Hay, silage, rice bran . .	Do.
7	Butter fat . .	Makerpura Farm, Baroda.	Ordinary ration containing no cotton seed.	Do.
8	Ghee . . .	Hosur cattle Farm.	4 lb. cotton seed, 1 lb. rice bran and 1 lb. cake.	Trace of precipitate after 25 minutes.
9	Butter fat . .	Palace Dairy, Baroda.	Ration containing cotton seed	Do.

[1] Pailheret, F. Cryoscopy of fats especially of butter and margarine; *Abs. J. Soc. Chem. Ind.* 28 (1909).

(b) Butter and ghee from buffalo.

No.	Description			3 c.c. acetic ether + 4 c.c. 93 per cent. alcohol + 1 grm. fat, kept at 30°C for ½ hr.
	Nature	Place from	Ration given to animal	
10	Butter fat . .	Pusa (Local dealer).	Ordinary ration containing no cotton seed.	No precipitate.
11	Do. . .	Do. Merchant .	Do. do. .	Do.
12	Ghee No. 3 .	Nagpur Farm .	Chunni and linseed cake in equal proportion.	Do.
13	Ghee No. 1 .	Do. .	Chunni, linseed cake and cotton seed (1 : 1 : 1).	Precipitate.
14	Ghee No. 2 .	Do. .	Chunni, linseed cake and cotton seed (1 : 1 : 3).	Do.
15	Butter fat . .	Makerpura Farm, Baroda.	Ordinary ration containing no cotton seed.	No precipitate.
16	Do. . .	Do. .	Ration containing cotton seed.	Precipitate.

From the above results, it will be seen that (1) no precipitate appeared in the case of butter or ghee prepared from cows or buffaloes which were not fed with cotton seed ; (2) a considerable amount of precipitate appeared in the case of butter fat or ghee prepared from *buffaloes fed with cotton seed ;* while in the case of *cows fed with cotton seed,* the butter fat or ghee yielded only a mere trace of precipitate by the test which could be ignored.

The method, therefore, fails only in the case of butter and ghee from buffaloes fed with cotton seed.

The fat in this case, however, has been found to give a reddish tinge with Halphen's test. Lighter colour has also been developed by Halphen's test with butter fat or ghee from cow given cotton seed in ration, while no colour appeared with samples prepared from animals not given cotton seed.

By a series of trials a second test was evolved which gave no precipitate or on'y a trace with butter fat from buffaloes given cotton seed in their rations, but which gave a precipitate with butter fat or ghee, obtained from cows or buffaloes, if adulterated with 10 per cent. animal fat.

This test simply consists in reversing the proportions of the reagents used in Test I, *i.e.*, 4 c.c. of acetic ether and 3 c.c. of 93 per cent. alcohol used and in all other respects it is carried out exactly as described for Test I. This test is referred to as Test II in the context.

No appreciable precipitate was obtained by Test II with any of the above 16 samples of butter fat or ghee, while a considerable quantity of the precipitate was obtained with a sample of cow's butter fat containing 10 per cent. animal fat.

The volumes of the precipitates obtained from adulterated butter fat by Test II are given below :—

Animal fat in cow's butter fat, per cent.	0	5	10	15	20	25
Volume of precipitate in 'urine tube' .	*Nil*	Trace	·1	·2	·4	·6

10 per cent. buffalo body fat added to a butter fat from a buffalo fed with cotton seed gave, by Test II, ·2 volume of precipitate in 'urine tube'.

It will thus be seen that the quantities of precipitates obtained by Tests I and II on the same sample vary considerably, so that unless the complete history of a sample of the butter or ghee is known, it is not possible to adopt these tests for the quantitative determination of the extent of adulteration. They will, however, easily detect an adulteration of butter fat and ghee with animal fat qualitatively, and when the history is known, the extent of adulteration can be found out by comparing the precipitate with those of artificially adulterated samples.

Application of the tests I and II to butter fat adulterated with vegetable ghee (hydrogenated oil) and oils.

Vegetable oils, such as cocoanut, olive, linseed, castor and mustard, have been found to yield no precipitate with either of the Tests I and II.

Vegetable ghee (hydrogenated oil), however, when mixed with butter fat yields, by Test I, smaller amounts of precipitate than that obtained when animal fat is mixed, as will be seen from the following figures :—

Vegetable ghee in butter fat, per cent. .	0	5	10	15	20
Weight of precipitate in grm.	0	·004	·0065	·014	·026

With Test II no precipitate appears unless the butter fat is very highly adulterated with vegetable ghee (more than 50 per cent.).

The vegetable origin of the adulterant can be definitely ascertained by phytosteryl acetate (crystals) test. Iodine values for vegetable ghee, animal fat and butter fat have been found to be 61·5, 21·5 and 29, respectively. So a high iodine value of a sample, which is giving a precipitate by Test I, will lead to the suspicion of the vegetable origin of the adulterant.

Application to the examination of commercial butters.

Having thus established the two tests for the detection of animal fat in ghee or butter fat, they were applied to a number of commercial butters from different parts of India with the object of finding out their genuineness.

Most of these samples gave a precipitate when tested with Test I. This is what was expected, as most of the samples were prepared in Bombay Presidency where milk of buffalo, which are fed with cotton seed, is generally used for making butters. With Halphen's test, these samples gave orange or red colouration (faint) according as they were artificially coloured or not thus confirming the above supposition.

The results obtained by Test II show that out of the 18 samples only one gave a precipitate corresponding to about 12 per cent. adulteration with animal fat.

The tests evolved, therefore, showed their applicability in the case of :—

I. Genuine butter and ghee from cow and buffalo given a great variety of rations including cotton seed.

II. Samples adulterated with animal fat and vegetable ghee.

III. Commercial butters from different parts of India.

The general usefulness of the tests for detection of adulteration of butter fat and ghee with animal fat and vegetable ghee is thus established. To distinguish between the animal or vegetable origin of the adulterant, determination of iodine value and phytosteryl acetate test should be resorted to.

Conclusion.

(1) Two tests were evolved for the detection of adulteration of butter and ghee especially with animal fat. They were based upon the solubility of butter fat and ghee in two definite mixtures of acetic ether (dry) and 93 per cent. alcohol under strictly controlled conditions of concentration and temperature, and the insolubility of the glycerides of higher fatty acids of animal fat in it.

(2) Test I consists in dissolving 1 grm. of melted fat in 3 c.c. of dry acetic ether and adding 4 c.c. of 93 per cent. alcohol to it at 30°C and leaving the mixture in a bath at 30°C for half an hour.

Pure butter fat and ghee (filtered through dry paper) from cow and buffalo which are not fed with cotton seed give no precipitate by this test, while adulteration to the extent of 5 per cent. or more with amimal fat produce precipitates which are proportional to the amounts of adulteration up to a certain limit (25 per cent.).

Adulteration of ghee and butter with 12 per cent. or more of vegetable ghee (hydrogenated product) can also be detected by Test I. The vegetable origin of the adulterant may in this case be established by the high iodine value and Phytosteryl acetate test.

(3) Test I, however, fails in the case of butter fat or ghee prepared from *buffaloes given cotton seed* in their ration, but such butters or ghee give orange or reddish tints with Halphen's test. Test II was evolved to deal with these cases.

(4) Test II consists in simply reversing the proportions of the reagents used in Test I, *i.e.*, 4 c.c. of acetic ether and 3 c.c. of 93 per cent. alcohol are used. The other conditions of Test I are maintained.

By this test butter fat and ghee prepared from cows or buffaloes given cotton seed in the ration as well as most of the commercial butters examined gave either no precipitate or only a mere trace, but adulterated samples containing 10 per cent. animal fat or more yielded appreciable amount of precipitate in half an hour.

I take this opportunity of expressing my thanks to the Government Departments of Agriculture of Madras, Bengal, Central Provinces, and the State Department of Agriculture, Baroda, for their courtesy in supplying us samples of butter and ghee, especially prepared from animals given particular kinds of rations. These enabled me to study the applicability of the tests to butter and ghee prepared from animal reared under varying conditions of climate and food.

Finally, I am grateful to Dr. W. H. Harrison, the Imperial Agricultural Chemist, for the keen interest he has taken in the work and constant encouragement he has given me during the investigation.

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THE APPLICATION OF THE ANTIMONY ELECTRODE TO THE DETERMINATION OF THE pH VALUE AND THE LIME REQUIREMENT OF SOILS.

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I. Introduction.

The antimony electrode was first employed by Uhl and Kestranek [1] for the electrometric titration of alkalis and acids and, shortly afterwards, Kolthoff and Hartong [2] made a more detailed and extensive study of the electrode and showed that it was a reliable hydrogen-ion indicator for the determination of pH values. The latter investigators found that the relationship between potential and H-ion concentrations at 14°C. measured against a N calomel electrode was as follows :—

$$E = \cdot 0415 + \cdot 0485 \text{ pH (from pH 1 to 5)}$$

$$E = \cdot 009 + \cdot 0536 \text{ pH (pH above 9)}$$

Recently Franke and Willaman [3] studied the application of the antimony electrode for the control of pulp and paper manufacture, and from a determination of

[1] Uhl, A., and Kestranek, W. 1923. Die elektrometrische Titration von Sauren und Basen mit der Antimon-Indikatorelektrode. *Monatsh. Chem.*, **44**, 29-34.

[2] Kolthoff, I. M., and Hartong, B. D. 1925. The antimony electrode as an indicator for hydrogen ions and its application in potentiometric titrations of acids and bases. *Rec. Trav. Chim Pays-Bas.*, **44**, 113-120.

[3] Franke, K. W., and Willaman, J. J. 1928. Measurement of hydrogen-ion concentration in the control of pulp and paper manufacture. *Jour. Indus. Engin, Chem.*, **20**, 87-95.

potentials measured against the N calomel electrode at 25°C. concluded that the relationship over a range of pH 1 to 12 could be expressed by the equation

$$E = \cdot 050 + \cdot 054 \text{ pH}$$

Accepting the formula of Franke and Willaman, Snyder [1] showed that the antimony electrode could be employed for the determination of the pH of soil suspensions and his investigations have been closely followed by those of Lava and Hemedes [2] who confirm the reliability of the electrode ; but from their measurements against a N calomel cell at 26—29°C. and using a quinhydrone electrode as reference, they deduce the following relationship

$$E = \cdot 047 + \cdot 055 \text{ pH}.$$

Tested in sugar solutions, the relationship found was

$$E = \cdot 052 + \cdot 057 \text{ pH}.$$

These observers also tested the electrode in soil suspensions and obtained in the majority of cases substantial agreement with the values obtained with a quinhydrone electrode, but in certain instances there was a marked divergence.

For several years a study has been made in this laboratory of various metallic electrodes and their applicability to the determination of pH values, the object being to obtain a robust and reliable method suitable for field work ; but although several electrodes such as molybdenum and tungsten were promising, the only one which gave uniformly concordant and reliable results over extended periods was antimony. Attention was therefore concentrated upon the antimony electrode and the results of our investigations, which have been developed upon very dissimilar lines to the previous work briefly reviewed above, are given in the following.

II. The antimony electrode as a pH indicator.

All previous work, with the exception of a few measurements by Snyder,[1] has dealt with potentiometric determinations made in solutions or suspensions which have been kept agitated or stirred. Our earlier investigations showed us that, although a quick and sharp equilibrium was obtained in buffer solutions under these conditions, a very good reading was also obtained when the liquids were at rest and, as this procedure eliminated cumbersome apparatus difficult of employment under field conditions, our investigations have been developed almost entirely under unstirred conditions.

The antimony electrodes employed were made by casting sticks in vertical moulds and were prepared from different qualities of antimony ranging from

[1] Snyder, E. F. 1928. The Application of the Antimony Electrode to the Determination of the pH values of soils. *Soil Science*, **26**, 107-112.

[2] Lava, V. G., and Hemedes, E. D. 1928. The behavior of the antimony electrode in buffered and unbuffered solutions. *Philip Agriculturist*, **17**, 337-349.

"regulus" to Merck's "extra pure." All the rods from whatsoever source gave similar readings when applied to buffer solutions, the pH values of which were determined by hydrogen electrodes ; but it was noticeable that a much quicker and sharper equilibrium was attained with the "extra pure" antimony rods and, consequently, most of our later measurements have been made by these. Where, however, great accuracy is not required, there is no practical objection to the employment of rods made from ordinary qualities of antimony.

In order to obtain a sharp equilibrium, it was found essential to cast the sticks in *vertical* moulds in order to obtain a uniform crystallization of the metal. Horizontally cast rods always showed uneven crystallization and gave violent fluctuations around the point of equilibrium which made it difficult to obtain very accurate readings with the potentiometer.

The vertically cast sticks are filed so as to remove any surface irregularities and holes, then smoothed with emery paper and finally polished with the finest carborundum powder and water. This treatment affects the electrode and it is only after an interval of several days that uniform and accurate readings can be assured. The polished electrodes soon tarnish when put into use and as this is usually accompanied by a decreased sensitiveness, it is necessary to take steps to keep the surface bright and clean. The quickest and best method is to dip the electrode into *aqua regia* for a few seconds, wash quickly in water and polish with a damp soft cloth. Instead of using *aqua regia*, it also suffices if the rods are first dipped into nitric acid, then into hydrochloric acid and finally washed and polished. Occasionally rods show symptom of "poisoning" due to accidental contact with mercury or metallic solution, but in all cases this treatment with the acids has restored their sensitiveness. Electrodes treated in this manner have been in constant use in this laboratory for over two years and show no signs of deterioration.

Our measurements of the electric potential in buffer solutions of known pH value using a saturated calomel cell as reference electrode amply confirm the observations of other investigators that the antimony electrode is an accurate indicator eminently suitable for the determination of pH values and there is, consequently, no necessity to emphasize this point further, but some reference is required at this point to the behaviour of the electrodes in stirred and unstirred solutions.

In making these comparisons, the buffer solutions were placed in a beaker and mechanically stirred or not as the case may be. Into the solution the saturated calomel electrode and the antimony electrode were dipped and the potential read off on a sensitive potentiometer. In all cases readings were taken until two consecutive readings taken at half-minute intervals agreed with each other and this reading was taken as the equilibrium point. This point was attained in agitated solutions usually within two minutes, but a longer period of usually about 5 to 10 minutes was needed with unstirred solutions. Some results obtained with rods made from an ordinary grade of "pure" antimony are given in the following table.

TABLE I.

Comparison of potentiometer readings in stirred and unstirred buffer solutions using a "pure" antimony electrode and a saturated calomel cell.

pH as determined by H. electrode	Readings in volts	
	stirred	unstirred
4·18	·1866	·2277
4·68	·2121	·2552
5·65	·2663	·3077
6·38	·3175	·3485
6·86	·3440	·3702
7·32	·3697	·3917
7·98	·4056	·4245
8·57	·4384	·4557
8·98	·4610	·4742

In all cases the readings obtained in *unstirred* solutions are appreciably higher than those obtained in *stirred* solutions. This observation is in agreement with that reported by Snyder [1] who estimated the pH values of soil emulsions with the electrode vessels both shaken and at rest, and the differences reported varied from ·0004 to ·0406 volt. This difference between the readings obtained under two conditions is probably due to a slow persistent drift in the case of the unstirred solutions, but if the point of equilibrium is taken as that when two consecutive half-minute readings agree, and the equation connecting potential and pH is calculated from these readings, then pH determinations can be made on unknown solutions with an accuracy more than sufficient for all practical purposes. Because of this very slow drift, it is also essential that the antimony electrode should be standardized by means of the instruments with which it is to be employed.

[1] *loc. cit.*

In order to carry out our investigation into the application of the antimony electrode to soils, only electrodes prepared from Merck's "extra pure" metal were used, and several were standardized by measuring the potential when dipped into *unstirred* buffer solutions using a *saturated* calomel electrode as reference, the temperature being about 30°C. The pH of the buffer solutions were determined by the hydrogen electrode. The average values obtained were as follows :—

TABLE II.

Standardization of the antimony electrode.

pH determined by H electrode	Volts (E)
4·14	·2298
4·67	·2592
5·71	·3110
6·41	·3425
6·85	·3631
7·32	·3841
7·97	·4158
8·57	·4519
8·99	·4766

The graph of these values is shown in Fig. 1 and demonstrates that the relation between E and pH is of the form E=a+b (pH).

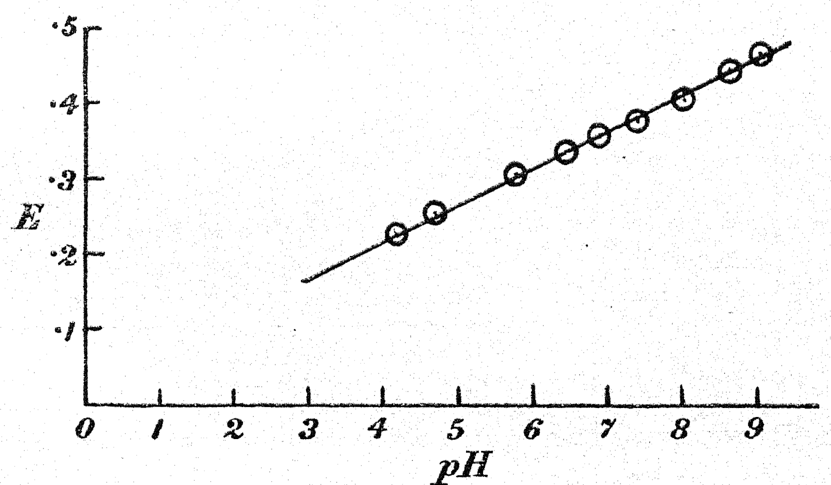


Fig. 1.

Graph showing relationship between potential and pH.

Employing the method of least squares, the relation between pH and potential in *unstirred* solutions against a saturated calomel electrode at 30°C. is

$$E = \cdot 0234 + \cdot 0498 \text{ pH}$$

$$\text{or pH} = \frac{E - \cdot 0234}{\cdot 0498}$$

The approximate relationship, $\text{pH} = \frac{E - .0234}{\cdot 05}$, has been employed in all our subsequent work.

III. The application of the antimony electrode for the determination of the pH value of soils.

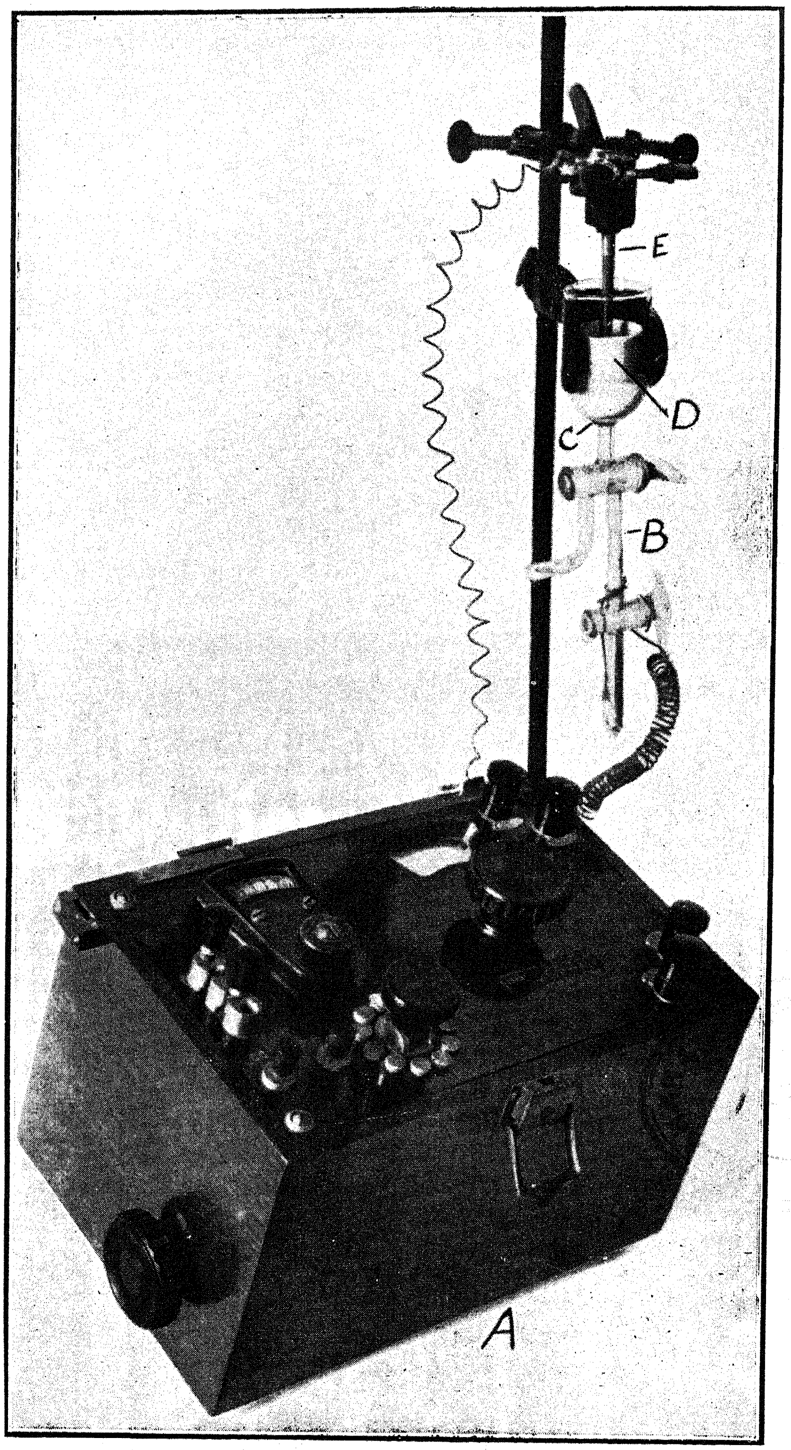
One of the main difficulties encountered in determining the pH value of a soil lies in the fact that the soil may give very different values according to the method adopted in preparing the soil solution or emulsion. Thus the value given by a soil suspension may be very different from the value obtained after the suspension has been allowed to settle, or clarified by centrifugalizing or filtration. In our experiments with the antimony electrode we obtained fairly uniform results under these different conditions with alkaline and neutral soils, but very variable values were obtained with acid soils and particularly with those of a lateritic character. As in the case of the hydrogen electrode, the most satisfactory results were obtained with soil suspensions, but difficulties were experienced through the settling out of the soil particles during the course of the determination by antimony electrodes in *unstirred* suspensions.

The difficulty was finally solved by the observation that, by merely dipping the antimony electrode into the moist soil, sharp satisfactory and reproducible readings were obtained which gave excellent agreement with the values obtained in soil suspensions by the hydrogen electrode. A number of observations made on Indian soils are given for comparison in Table III.

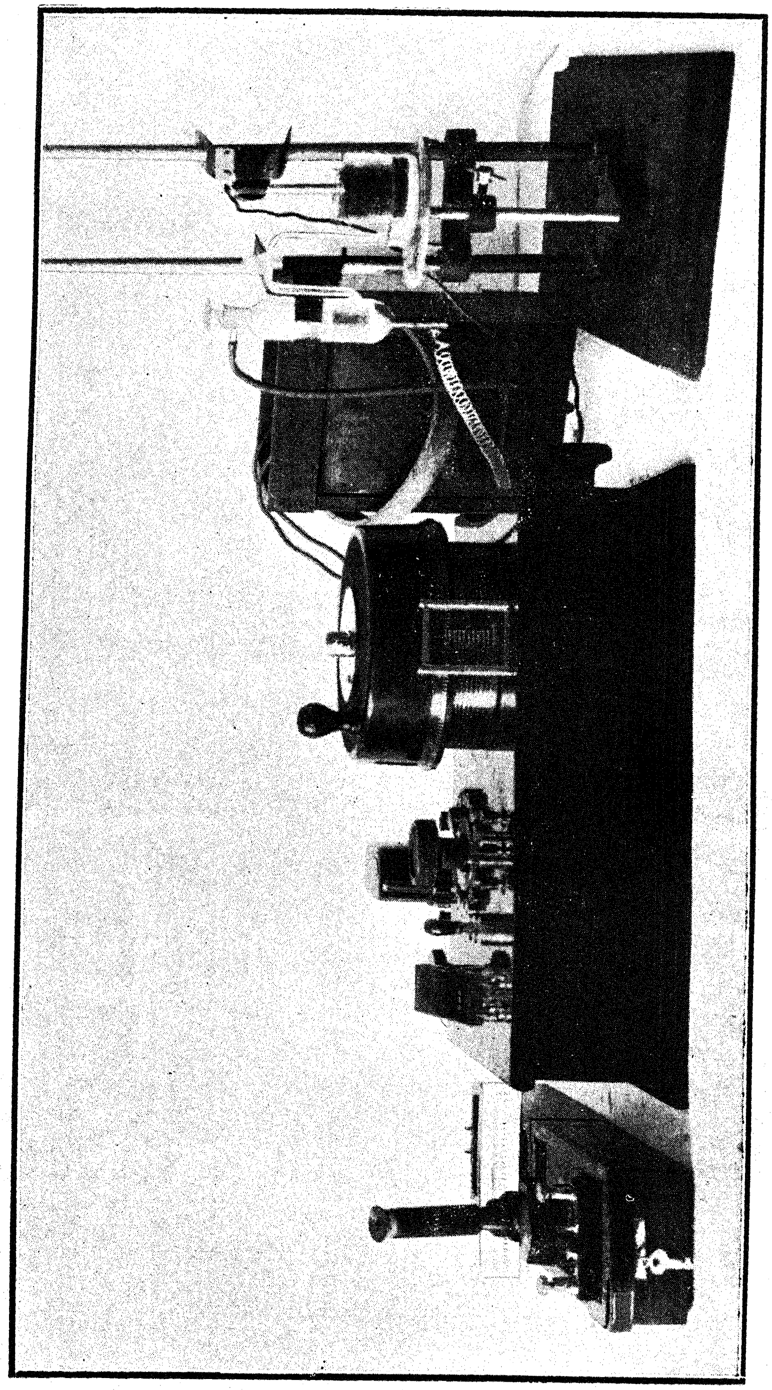
TABLE III.

Comparison of pH values obtained by the antimony electrode dipped into the moist soil and those by the hydrogen electrode in soil suspensions.

Soil	pH by hydrogen electrode in soil suspension	pH by antimony electrode dipped into moist soil
Dacca red soil	4·44	4·68
Burma laterite II	4·46	4·44
Burma laterite I	4·73	4·63



Field apparatus for the determination of soil acidity.



Laboratory apparatus for the determination of soil pH value.

TABLE III—*contd.*

Comparison of pH values obtained by the antimony electrode dipped into the moist soil and those by the hydrogen electrode in soil suspensions— contd.

Soil	pH by hydrogen electrode in soil suspension	pH by antimony electrode dipped into moist soil
Assam acid	4·58	4·77
Wellington laterite	4·88	4·95
Travancore (Kari soil)	5·36	5·57
Siliguri (Humus)	5·65	5·68
Darjeeling (Humus)	5·64	5·61
Dacca laterite	5·86	6·00
Shillong	6·12	6·42
Ramgarh	7·02	7·21
Pusa	8·21	8·38
Coimbatore	8·48	8·64
Nandyal (black cotton)	9·04	9·05

This method of applying the electrode to the moistened soil is therefore strictly comparable to the hydrogen electrode and experience over two years has shown it to be convenient, quick, reliable and reproducible. In carrying out the tests, the soil is placed in a glass vessel of suitable dimensions, the bottom of which consists of a porous plate. Water is added in sufficient quantity to give a pasty mass when stirred and the glass vessel is then placed in a shallow dish containing salt solution into which dips the end of a saturated calomel electrode. The antimony rod is dipped into the moist soil and there is thus formed a salt bridge between the two electrodes, the terminals of which are connected to a sensitive potentiometer. It has been found advantageous to stir the soil after the addition of water with the antimony electrode itself, which is then removed and the adhering soil removed by polishing with a clean soft rag before replacing in moist soil for the readings to be taken. By adopting this procedure, a quicker and sharper equilibrium is attained.

The great advantage of employing the antimony rod in this manner is the elimination of tedious manipulative processes and complicated apparatus, thus enabling a portable outfit to be constructed capable of easy application to field work. Such a field apparatus is shown in Plate I and consists of a portable potentiometer (A),

a portable saturated calomel electrode (B), provided with a cup (C), containing saturated KCl solution into which a glass soil container (D) with a porous bottom is dipped. The antimony electrode (E) in turn dips into the moist soil contained in (D).

A more elaborate set up for use in the laboratory is shown in Plate II.

As most soil work is carried out between pH 4 and pH 9 and as an accuracy of ·1 pH is usually all that is necessary for ordinary soil investigations, the following method for standardising the rods will be found quick and convenient. 100 c.c. of B. D. H. Universal Buffer solution [1] diluted with 100 c.c. of water is placed in a vessel into which dip the calomel and antimony electrodes, and $\frac{N}{5}$ NaOH is run in 5 c.c. at a time commencing with the addition of 10 c.c. After each addition the potential is read off, the point of equilibrium being taken as that when two consecutive half-minute readings agree with each other. As the values of the Universal Buffer solution are only approximately given by the formula supplied by the makers, it is necessary to determine the actual pH at each point of measurement by means of the hydrogen electrode. These values, when plotted against the corresponding potential readings obtained with the antimony rod, yield a straight line graph from which the relationship between pH and the potential is easily determined.

Experience over a number of years shows that this method of standardization is sufficiently accurate for practical purposes and the relationship obtained agrees well with that given by more accurately prepared buffer solutions and moreover saves a considerable expenditure of time.

IV. The determination of the lime requirement of soils by means of the antimony electrode.

The method previously outlined, of determining the pH value of a moist soil by merely dipping an antimony electrode into it, affords also a quick and accurate method of estimating the amount of lime required to be added to a soil in order to bring the latter to any predetermined pH value.

All that is necessary is this :—Weigh out a number of 50 gram portions of the soil into separate beakers ; add to each beaker a measured quantity of saturated lime-water made up in each case to a total volume of 40 c.c. with recently boiled distilled water, and stirring the whole well. After an interval of half an hour, during which the beakers are occasionally stirred, the moist soil is transferred to the porous vessel and the pH of the mixture determined according to the method described in part III. At the temperature at which our experiments were carried out, *viz.*, about 30°C., the lime-water used contained ·00112 gram CaO per c.c. and, as in all cases 50 grams of soil were employed in the test, this is equivalent to an addition of 22·4 parts of CaO to a million parts of soil per c.c of lime-water used.

A number of tests were carried out with a variety of acid soils obtained from different parts of India and Burma and the results are given in Table IV.

[1] Prepared according to the formula of Dr. E. B. R. Prideaux and Mr. A. T. Ward.

TABLE IV.

Showing lime requirements of various acid soils from India and Burma.

c.c. saturated lime-water per 50 grams soil	pH value of mixtures of soil and lime-water									
	Jorhat A	Shillong	Dacca A	Assam	Dacca B	Jorhat B	Burma A	Siliguri (humus acidity)	Welling-ton	Burma B
0	6·37	6·53	6·16	5·00	5·47	4·68	5·36	5·75	5·29	4·71
5	7·22	6·97	6·83	5·49	..	5·01	..	..	5·58	..
10	7·63	7·21	7·36	6·07	5·95	5·81	5·88	6·17	5·82	..
15	8·16	..	..	6·49	6·31	6·37	6·13	..	6·05	5·25
20	..	..	..	6·91	6·75	6·79	6·34	6·62	6·17	..
25	..	..	..	7·27	7·04	7·05	6·66	..	6·34	5·56
30	..	..	..	7·52	7·38	7·56	6·90	6·88	6·52	..
35	..	..	..	7·83	..	..	7·43	..	6·73	5·85
40	..	..	..	7·93	..	8·34	..	7·23	6·91	..
45	..	..	..	..	..	..	..	..	7·02	..
55	..	..	..	..	..	..	..	..	..	6·88

The process is in reality one of finding the titration curve of a soil by means of saturated lime-water and the curves obtained are shown in Fig. 2. The point of

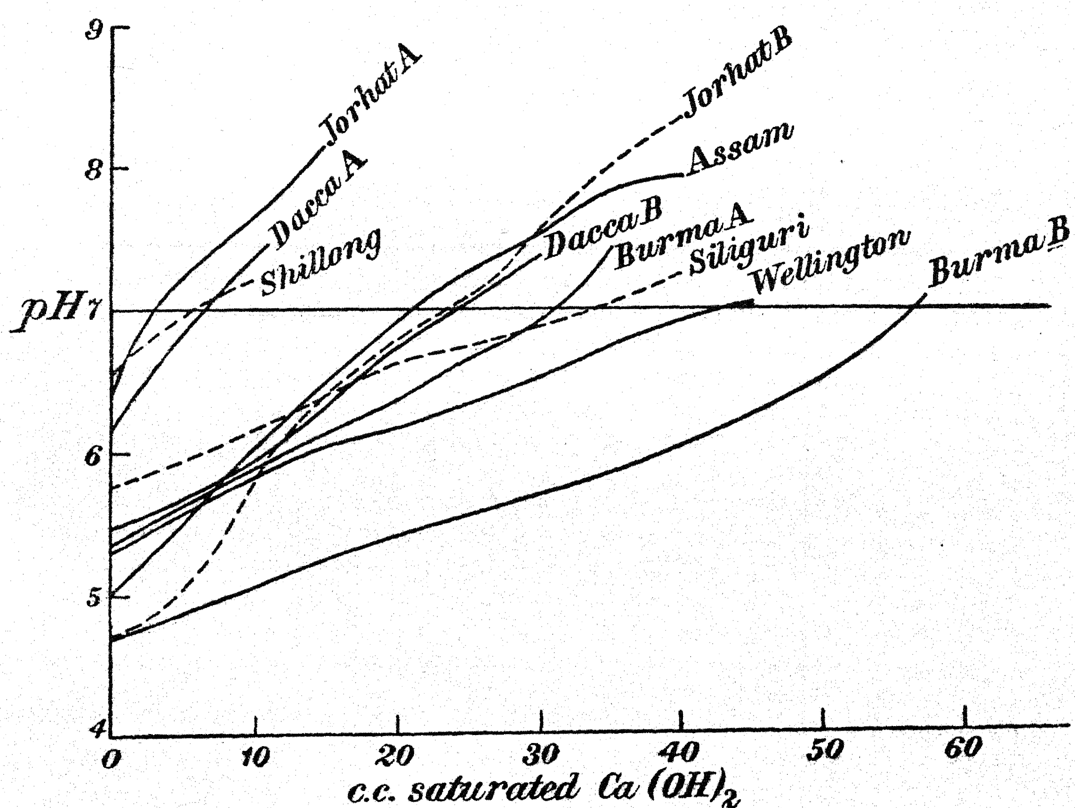


Fig. 2.
Titration Curves of Indian Soils.

intersection of each curve with the ordinate pH 7 determines the lime requirements of the soil to produce neutrality. The following values are thus obtained for the soils under review :—

TABLE V.

Soil	c.c. of saturated lime-water required to give pH 7 with 50 grm. soil	Lime requirement parts per million to produce neutrality
Jorhat A	3·2	72
Shillong	5·6	125
Dacca A	6·5	145
Assam	21·3	477
Dacca B	24·2	542
Jorhat B	24·0	538
Burma A	31·1	697
Siliguri	34·1	764
Wellington	43·8	982
Burma B	56·2	1260

In a similar manner it is possible by obtaining the intersection points of the curves with other pH ordinates to determine the lime requirement for that value. The results obtained are reproducible and, even when different amounts of soil are taken for the determination, the lime requirement value does not vary materially. Furthermore, tests carried out when the soil was permitted to remain in contact with the lime-water for varying periods of time gave values agreeing with each other.

This method of estimating the lime requirement of a soil therefore yields definite reproducible values, and is, moreover, one capable of being easily carried out under field conditions. Being applied to the soil in bulk, and not to an extract of the soil, it would appear that the values obtained represent the true lime requirement of a soil in that they are a very near approximation to the conditions which obtain when lime is applied to the soil *in situ* and measure, not only the amount of lime necessary to neutralise the soil acidity, but also the lime which is absorbed by the soil through reactions due to base exchange, etc. This is borne out by the fact that when other alkalis, *e.g.*, caustic soda, are employed in place of the lime-water in equivalent strength, very dissimilar volumes are required to reach the same pH. This is shown in the following table when a soil was titrated with $\frac{N}{25}$ solutions of lime-water and caustic soda.

TABLE VI.

Showing the pH value obtained when 50 grams of a soil is treated with similar volumes of $\frac{N}{25}$ solutions of CaO and NaOH.

c.c. $\frac{N}{25}$ alkali added	pH value with CaO	pH value with NaOH
0	4·68	4·68
5	5·07	5·78
10	5·81	6·51
15	6·37	7·10
20	6·79	7·53
25	7·05	7·83
30	7·56	8·28
40	8·34	....

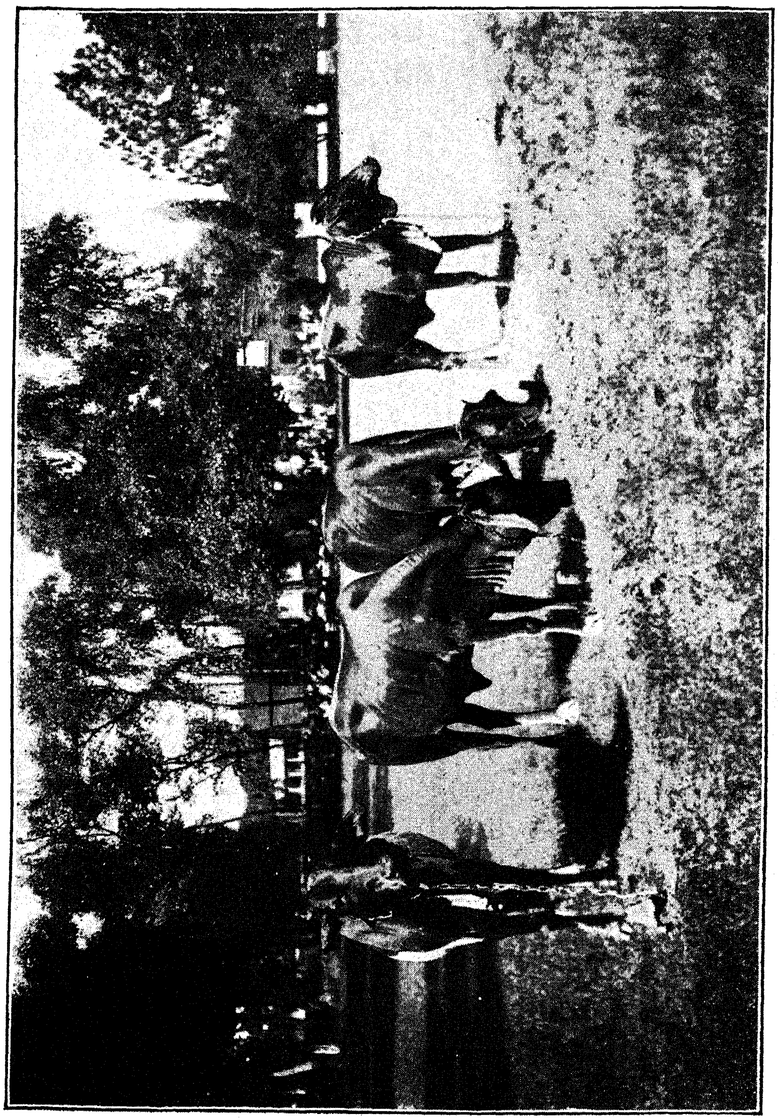
Consequently, in order to determine the lime requirement of a soil, it is necessary that the operation of titrating it should be done only with lime-water. It is not permissible to employ other alkaline solutions.

Summary.

1. The antimony electrode forms a robust and reliable indicator of pH values and can be employed for their accurate estimation either in stirred or unstirred solutions.
2. The potentiometric readings obtained under *unstirred* conditions are somewhat higher than those found with *stirred* solutions, but the relationship between pH and potential is of a simple character expressed by the formula $E=a+b$ (pH).
3. The pH values obtained by dipping an antimony electrode into moistened soil which is connected by a suitable salt bridge to a saturated calomel electrode are almost identical with those obtained by the hydrogen electrode in soil emulsions.
4. This method of applying the antimony electrode permits of the employment of a simple and convenient apparatus for field work.
5. The method also permits of titration curves being obtained for acid soils in the field, from which the lime requirement of a soil for any predetermined pH value is readily computed.

MGIPC—M—III-1-9—2-8-29—500.

PLATE I.



LEFT TO RIGHT = MONTGOMERY HEIFERS Nos. 116, 115, 117, 120.

SOME DIGESTIBILITY TRIALS ON INDIAN FEEDING STUFFS, PART IV.

SOME PUNJAB HAYS, II.

BY

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In an earlier paper[1] of this series of digestibility trials, an account was given of experiments carried out during the winter of 1926-27 to ascertain the value of some Punjab hays as maintenance rations for dry cows. It was shown that hays from some districts of the Punjab were adequate as maintenance rations, while others were not, and an indication was given of the amount of added wheat bran required to be added to the deficient hays in order to bring them to a maintenance standard.

This work was continued during the cold weather of 1927-28 using four heifers designated by numbers 115, 116, 117 and 120 (Plate I), and employing hays supplied by the Military Grass Farms, collected from Rawalpindi, Murree, Amballa and Lahore. An account is given of this work in the following paper from which it will be seen that only one of the four hays tested, namely, that from Amballa, came up to maintenance standard. The amount of added concentrate in the form of wheat bran required to be added to the others has been determined.

Statement showing the age and weight of the heifers under experiment.

No. of heifer	Average of daily body weight	Date of birth	Age on 9th November 1927		
			Years	Months	Days
	lb.				
115	370	4th July 1925	2	4	5
116	511	6th July 1925	2	4	3
117	435	9th July 1925	2	4	0
120	347	28th Oct. 1925	2	0	11

[1] Lander, P. E., and Dharmani, Pandit Lal Chand. Some Digestibility Trials on Indian Feeding Stuffs, III. Some Punjab Hays. *Mem. Dept. Agri. India, Chem. Series,* Vol. IX, No. 7. April 1928.

All the heifers were of the Montgomery breed and between 2 and 2½ years old and were very similar in all other respects.

The general method of procedure followed in these trials was the same as that described in the earlier paper[1], in every case a non-experimental period of about a fortnight's duration intervening between the different dietary periods.

The actual experimental periods and the rations used are shown in the following table :—

TABLE I.

I. 23rd November 1927 to 6th December 1927	Rawalpindi hay	Heifers 115 and 116.
Ditto	Murree hay	Heifers 117 and 120.
II. 11th December 1927 to 13th January 1928	Rawalpindi hay and bran	Heifers 115 and 116.
Ditto	Murree hay and bran	Heifers 117 and 120.
III. 14th January 1928 to 12th February 1928	Farm diet (Non-experimental)	Heifers 115, 116, 117 and 120.
IV. 20th February 1928 to 17th March 1928	Lahore hay	Heifers 115 and 116.
Ditto	Amballa hay	Heifers 117 and 120.
V. 4th April 1928 to 17th April 1928	Lahore hay and bran	Heifers 115 and 116.

At the end of the second period the animals appeared to be somewhat out of condition and in order to tone them up they were put temporarily on a richer diet. Heifers 115 and 116 were given bran and gram in addition to Rawalpindi hay and heifers 117 and 120 were given bran and green oats in addition to Murree hay. No experimental data were collected during this period, but the animals were weighed daily. The non-experimental period with Lahore hay preceding the fourth period was started on 13th February 1928.

Description of the Hays.

Rawalpindi and Murree grass hays.

These hays were representative of grass collected from the neighbourhoods of the Military Grass Farms at Rawalpindi and Murree in October 1927, the sample from Murree having been collected somewhat earlier than the other, but both were representative of the "pre-milk stage".

Both hays consisted mainly of a mixture of *Andropogon contortus* Lin. known in the Punjab as "Suryala" and *Anthistiria anathera* known in the vernacular as "Loonder". The inflorescence of the former contained many fine spiral spikes which caused some inconvenience to the animals when fed and perhaps detracted from the digestibility of the feed.

[1] Lander, P. E., and Dharmani, Pandit Lal Chand. Some Digestibility Trials on Indian Feeding Stuffs, III. Some Punjab Hays. *Mem. Dept. Agri. India, Chem. Series*, Vol. IX, No. 7. April 1928.

The Lahore hay.

The grasses constituting this hay were collected from the Lahore Cantonment area in October and November 1927 and consisted mainly of a mixture of four grasses, *viz.*, (*a*) *Andropogon Sorghum* (Brot) " Baru ", (*b*) *Iseilema wightii* (Anders) " Ganni ", (*c*) *Setaria glauca* (Beaur) " Ban Kangna " and (*d*) *Andropogon Iwarancusa* (Jones) var. Laniger " Khavi".

The major portion of this hay appears to have been made from grasses collected somewhat later than the " milk stage", as much of the inflorescence was lost.

The Amballa hay.

This was composed of a mixture of five grasses collected within the Amballa Cantonment area in October and early November 1927, *viz.*, (*a*) *Pennisetum cenchroides* (Rich) " Anjan ", (*b*) *Apluda varia* (Hack) var. " Aristata ", (*c*) *Paspapalum Sanguinale,* (*d*) *Setaria Intermedia* R. & S., (*e*) *Panicum Ramosum* " Kura ".

This hay had obviously been made from grasses cut at an earlier stage than that of the Lahore hay and contained a far greater quantity of inflorescence, a fact which may account for its higher nutritive value.

Table II shows the ordinary chemical analyses of the hays, and in the same table the analyses of the mineral ingredients are given.

Table III shows details of the dietary standards and ratios of the feeds of the different animals, while Table IV shows the digestibility co-efficients obtained. Fig. 1 gives the growth curves obtained throughout—all the animals having been weighed daily.

TABLE II.

A. Chemical composition.

Name of the feed	Moisture	Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Murree hay	6·60	93·40	6·86	1·78	40·99	3·44	40·33
Rawalpindi hay	8·50	91·50	7·91	1·73	42·01	3·13	36·72
Amballa hay	8·85	91·15	9·78	1·29	32·66	5·06	42·36
Lahore hay	10·10	89·90	8·77	1·26	34·85	3·94	41·08
Wheat bran	9·24	90·76	4·83	3·79	11·53	14·13	56·48

B. Mineral matter in 1,000 lb. of the feed.

Name of the feed	Phosphates P_2O_5	Calcium CaO	Sodium Na_2O	Potassium K_2O	Magnesium MgO	Manganese Mn_3O_4	Aluminium Al_2O_3	Iron Fe_2O_3	Sulphate So_4	Chlorides Cl.	Insoluble Residue
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
Murree hay	0·99	8·48	4·53	7·60	2·39	0·41	0·22	0·85	1·10	0·97	43·08
Rawalpindi hay	1·14	8·45	3·89	7·85	2·60	0·44	0·32	1·08	1·30	0·90	51·57
Amballa hay	6·06	5·16	7·94	23·04	2·19	0·51	1·64	0·55	4·93	4·44	40·68
Lahore hay	3·12	6·00	4·35	16·28	1·83	0·39	1·26	0·35	3·93	4·03	46·31
Wheat bran	20·00	3·56	1·35	8·95	6·57	0·51	0·10	0·15	5·60	..	1·35

TABLE III.

Dietary standards.

Period	No. of heifer	Average of daily body weight	Feed eaten per day		Per 100 lb. of food: Starch equivalents	Per 100 lb. of food: Protein	Albuminoid Ratio 1 :	Daily nitrogen balance in grams	Starch equivalents per day	Protein per day
		lb.		lb.	lb.	lb.			lb.	lb.
23rd Nov. 1927 to 6th Dec. 1927.	115	370	Rawalpindi hay	4·1	22·44	0·63	73·0	—4·95	0·92	0·03
Do.	116	511	Do.	7·3	17·78	0·69	60·8	—7·03	1·30	0·05
Do.	117	435	Murree hay	5·7	18·59	0·53	79·7	—8·15	1·06	0·03
Do.	120	347	Do.	5·1	22·59	0·59	78·0	—4·97	1·15	0·03
20th Feb. to 17th Mar. 1928.	115	379	Lahore hay	6·6	27·04	1·52	30·3	—1·80	1·78	0·10
Do.	116	492	Do.	8·7	25·53	1·50	29·7	—0·50	2·22	0·13
Do.	117	467	Amballa hay	8·7	22·87	2·21	18·0	2·07	1·97	0·19
Do.	120	376	Do.	7·8	24·97	2·31	18·1	3·35	1·95	0·18
11th Dec. 1927 to 13th Jan. 1928.	115	365	Rawalpindi hay and bran.	4·9 1·5	..	..	14·3	7·05	1·71	0·20
Do.	116	490	Do.	7·6 1·5	..	..	19·0	4·73	2·21	0·21
Do.	117	419	Murree hay and bran	5·4 2·0	..	..	13·0	8·83	2·14	0·26
Do.	120	335	Do.	4·3 1·0	..	..	20·5	3·87	1·38	0·14
4th to 17th April 1928.	115	392	Lahore hay and bran	7·6 0·5	..	..	21·3	1·79	1·98	0·16
Do.	116	511	Do.	9·0 0·5	..	..	21·4	1·80	2·60	0·20

Table IV.

Digestibility factors.

Period	No. of heifer	Average of daily body weight	Feed eaten per day		Digestibility Coefficients						Nutrients digested per day					
					Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract	Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract
					Hays alone.						Hays alone.					
		lb.		lb.							lb.	lb.	lb.	lb.	lb.	lb.
23rd Nov. to 6th Dec. 1927.	115	370	Rawalpindi hay	4·1	50·94	9·38	49·30	67·50	20·31	43·52	1·91	0·03	0·04	1·16	0·03	0·66
Do.	116	511	Do.	7·3	45·52	8·62	46·15	62·22	21·74	36·94	3·04	0·05	0·06	1·91	0·05	0·99
Do.	117	435	Murree hay	5·7	43·60	..	40·00	63·25	15·00	35·65	2·32	..	0·04	1·48	0·03	0·82
Do.	120	347	Do.	5·1	49·06	..	33·33	66·98	16·67	42·24	2·34	..	0·03	1·40	0·03	0·87
20th Feb. to 17th Mar. 1928.	115	379	Lahore hay	6·6	55·14	30·00	25·00	66·52	38·47	53·51	3·27	0·18	0·02	1·53	0·10	1·45
Do.	116	492	Do.	8·7	52·94	22·37	27·27	63·70	38·24	52·10	4·14	0·17	0·03	1·93	0·13	1·86
Do.	117	467	Amballa hay	8·7	46·82	13·10	36·37	55·51	43·19	48·63	3·67	0·11	0·04	1·56	0·19	1·77
Do.	120	376	Do.	7·8	50·07	22·37	40·00	57·65	45·01	51·52	3·56	0·17	0·04	1·47	0·18	1·70
					Hay and Bran.						Hay and Bran.					
11th Dec. 1927 to 13th Jan. 1928.	115	365	Rawalpindi hay Wheat bran	4·9 1·5	50·05	11·50	55·63	59·34	53·27	48·07	2·93	0·05	0·08	1·33	0·20	1·28
Do.	116	490	Ditto	7·6 1·5	48·84	10·68	55·02	59·18	45·78	46·31	4·07	0·07	0·10	2·00	0·21	1·69
Do.	117	419	Murree hay Wheat bran	5·4 2·0	48·62	..	64·15	53·97	54·68	50·80	3·35	..	0·11	1·33	0·26	1·69
Do.	120	335	Ditto	4·3 1·0	47·98	..	56·15	56·44	48·61	48·28	2·36	..	0·06	1·06	0·14	1·11
4th to 17th April 1928.	115	392	Lahore hay Wheat bran	7·6 0·5	50·66	29·67	36·52	60·97	42·97	48·10	3·69	0·21	0·04	1·65	0·16	1·67
Do.	116	511	Ditto	9·0 0·5	54·87	37·58	34·59	64·89	46·61	51·91	4·71	0·31	0·05	2·08	0·20	2·08

CURVE SHOWING FLUCTUATIONS IN DAILY BODY WEIGHTS OF THE ANIMALS

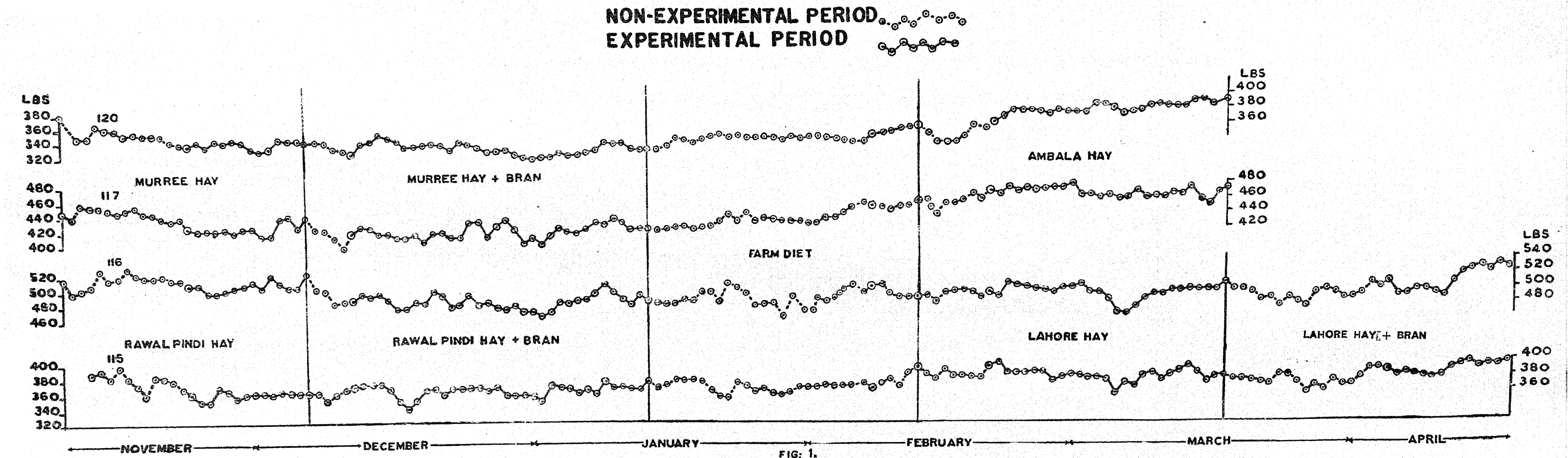

FIG: 1.

Feeding Trials with Individual hays.

(*A*) *Amballa hay.*

Reference to Table II shows that this hay was richer than any of the others in protein, with the comparatively high figure of 5·06 per cent. The total mineral content was also high, while the crude fibre was low. The same table (B) shows that the phosphorus, potassium and sodium contents were all much higher than in any of the other hays, the phosphorus content being the highest so far met with in any of the Punjab hays.

These features are reflected in the results obtained during the trials when this hay proved itself to be a maintenance ration both from the positive daily nitrogen balances, and from the upward trend of the weight curve of the animals to which it was fed.

From Table III we also see that the digestible protein is higher than that of any of the other hays, being almost double that of the Lahore hay, and three times that of the Rawalpindi hay, and about four times that of the Murree hay.

The albuminoid ratio is also much narrower than for the others and the feeding trials revealed the satisfactory nature of the Amballa hay as a maintenance ration for heifers of the age and weight of those employed.

As previously stated, this hay was mostly made from " Anjan " grass. The grass hay from Sialkot examined last year and reported in a previous publication[1] was also made mostly from " Anjan " grass and was likewise found to be a maintenance ration.

(*B*) *Rawalpindi hay.*

Two heifers 115 and 116 weighing 370 and 511 lb. respectively were fed on Rawalpindi hay for fourteen days following a non-experimental period of the same duration, when it was found that the average daily loss in nitrogen during that period was 4·95 and 7·03 grams respectively, obviously indicating that this hay did not constitute a maintenance ration ; wheat bran was accordingly added to the ration in order to bring it up to maintenance standard.

In the trials conducted last year it was found that 1 lb. of wheat bran effects an added daily nitrogen retention of 5·56 grams, when hay from Jullundur was used as a basal ration, and as the Rawalpindi and Jullundur hays are roughages of very similar composition, this figure was accepted as a working basis.

Assuming then that the efficiency of wheat bran fed with Rawalpindi hay to be the same as when fed with Jullundur hay, 0·89 and 1·26 lb. of wheat bran when added to the Rawalpindi hay in the feeds of heifers 115 and 116 respectively should be expected to bring the ration up to a maintenance level.

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[1] Lander, P. E., and Dharmani, Pandit Lal Chand. Some Digestibility Trials on Indian Feeding Stuffs, III. Some Punjab Hays. *Mem. Dept. Agri. India, Chem. Series,* Vol. IX, No. 7. April 1928.

In order, however, to arrive at practical figures with sufficient margin for individual error, the quantities of wheat bran added to the Rawalpindi hay were 1·5 lb. for each animal. Thus heifer No. 115 was being fed more than the theoretical quantity required so that her diet should be well over a maintenance figure, while heifer No. 116 would be rather near the margin. The experimental period lasted from 11th December 1927 to 13th January 1928, and during this period the average daily nitrogen retention figures for the two animals worked out at 7·05 and 4·73 grams, respectively.

Thus with heifer No. 115, it is clear that when losing 4·95 grams of nitrogen per day on a Rawalpindi hay ration, the addition of 1·5 lb. of bran per day converts this loss into a gain of 7·05 grams nitrogen per day.

One and-a-half lb. of added bran, therefore, effect a daily nitrogen gain of 4·95 *plus* 7·05 or 12 grams, or 8 grams per pound of bran fed. Heifer No. 116 was losing 7·03 grams per day and in this case the addition of 1·5 lb. bran per diem effects an average daily nitrogen gain of 7·03 *plus* 4·73 grams, or 11·76, *i.e.*, 7·84 grams per pound of bran fed, a figure which agrees closely with that obtained for heifer No. 115.

From these results, it may therefore be assumed that 1 lb. of bran can repair a nitrogen deficiency to the extent of 7·92 grams per day when Rawalpindi hay is fed *ad lib.*, and from these figures it is possible to calculate on a theoretical basis the exact quantities of bran that should be added to Rawalpindi hay in order to bring the heifers into nitrogen equilibrium. Heifer No. 115 who was losing 4·95 grams per day will need 0·63 lb. of bran and heifer 116 losing 7·03 grams per day will need 0·89 lb. of bran.

The weights of the 2 animals being 370 and 511 lb. respectively, it may be concluded that for heifers averaging from 400 to 500 lb. in weight an addition of one to one and a quarter lb. of bran will be required when a roughage such as that represented by the Rawalpindi hay is fed, in order to effect a maintenance ration.

(*C*) *Murree hay.*

In order to obtain similar data for Murree hay, heifers 117 and 120 were fed Murree hay alone *ad lib.* for a fortnight from 23rd November to 6th December 1927, this period being preceded by the usual non-experimental period of about a fortnight. As a result of this ration, heifer No. 117 weighing 435 lb. lost on an average 8·15 grams of nitrogen per day, while heifer 120 weighing 347 lb. lost 4·97 grams per day. It was found in similar feeding trials last year that 1 lb. bran when fed with Jutogh hay given *ad lib.* as a basal ration effected a nitrogen retention of 5·37 grams per day, and as Murree and Jutogh hays are roughages of similar type, we have worked on the same assumption as in the case of Rawalpindi hay mentioned above, so that 1 lb. of bran may be expected to effect a gain of 5·37 grams of digestible nitrogen, a quantity which should repair the nitrogen deficiency in the case of heifer 120, while 1·52 lb. of bran would be required to bring the dietary of heifer 117 up to the maintenance level.

In order, however, to arrive at practical figures with a sufficient margin for individual error, 1 lb. and 2 lb. of bran were added to the rations of heifers 120 and 117 respectively. Thus heifer 120 was getting just sufficient, while heifer 117 was getting more than the theoretical quantity. Both these animals were put on the ration of Murree hay and bran on the afternoon of the 6th December 1927 and the experimental period lasted for about a month from 11th December 1927 to 13th January 1928.

The figures for the average daily nitrogen balance for the two heifers 117 and 120 worked out at 8·83 and 3·87 respectively.

Thus heifer 117 loses 8·15 grams of nitrogen per day on ration of Murree hay alone, this negative figure being brought to a positive one of 8·83 grams by the addition of 2 lb. bran daily. The two lb. of bran, therefore, effected a total nitrogen gain of 16·98 grams or 8·49 grams per lb. of bran fed.

Correspondingly heifer 120 which was fed one lb. bran per diem converted a daily loss of 4·97 grams nitrogen into a daily gain of 3·87 or a total gain of 8·84 which agrees with the figure 8·49 obtained above for heifer 117.

These facts reveal that one lb. bran can repair a nitrogen deficiency to the extent of 8·67 grams per day when hay such as that represented by Murree hay is fed *ad lib.* to heifers.

From the above data the exact quantities of bran required to be added to the ration of heifers 117 and 120 to bring them to nitrogen equilibrium are 0·94 lb. and 0·50 respectively.

The body weights of the heifers 117 and 120 were 419 and 335 lb. respectively, so that the quantity of added bran required for animal weighing from 350 to 450 lb. when fed Murree hay *ad lib.* is from 0·75 to 1 lb. in order to effect a maintenance ration.

(*D*) *The Lahore hay.*

This hay was richer than those from Rawalpindi and Murree in all constituents save the fat and nitrogen free extract. The experimental period lasted about a month but the ration was not up to a maintenance standard as both heifers 115 and 116 lost nitrogen at the rate of 1·80 and 0·50 grams per day respectively (Table V). Wheat bran was then added to the ration, the experimental period lasting from 4th to 17th April 1928.

TABLE V.

Showing details of daily nitrogen balance in grams.

Period	No. of heifer	Feed	Intake		Outgo		Brushings	Total intake	Total outgo	Balance
			Hay	Concentrates	Dung	Urine				
23rd Nov. to 6th Dec. 1927.	115	Rawalpindi hay	9·30	..	7·42	6·83	Traces	9·30	14·25	—4·95
Do.	116	Do.	16·56	..	12·98	10·61		16·56	23·59	—7·03
Do.	117	Murree hay	11·27	..	10·53	8·89		11·27	19·42	—8·15
Do.	120	Do.	8·57	..	7·84	5·70		8·57	13·54	—4·97
20th Feb. to 17th Mar. 1928.	115	Lahore hay	18·66	..	12·56	7·90		18·66	20·46	—1·80
Do.	116	Do.	24·80	..	14·96	10·34		24·80	25·30	—0·50
Do.	117	Amballa hay	31·68	..	18·00	11·61		31·68	29·61	2·07
Do.	120	Do.	28·05	..	15·74	8·96		28·05	24·70	3·35
11th Dec. 1927 to 13th Jan. 1928.	115	Rawalpindi hay and bran.	11·08	15·38	12·09	7·32		26·46	19·41	7·05
Do.	116	Do.	16·73	15·38	16·72	10·66		32·11	27·38	4·73
Do.	117	Murree hay and bran.	13·29	20·50	14·78	10·18		33·79	24·96	8·83
Do.	120	Do.	10·23	10·25	10·36	6·25		20·48	16·61	3·87
4th to 17th April 1928.	115	Lahore hay and bran.	21·72	5·13	15·32	9·74		26·85	25·06	1·79
Do.	116	Do.	25·83	5·13	16·52	12·64		30·96	29·16	1·80

On the basis of experience gained from the results of the work on Rawalpindi and Murree hay and also with added bran, half a pound of bran was added to the Lahore hay ration per diem, with the result that the average daily nitrogen figures obtained during the experimental period were 1·79 and 1·80 (positive) respectively.

Thus heifer 115 shows a total nitrogen gain per day of 1·80 *plus* 1·79 for half a lb. of added bran so that one lb. represents $2 \times (1{\cdot}80$ *plus* $1{\cdot}79)$ or 7·18 grams. The corresponding figure for heifer 116 works out at 4·60 grams of nitrogen retained per pound of bran fed. These figures are somewhat disappointing but indicate nevertheless that the addition of half a pound of bran per day to the Lahore hay would bring it to a maintenance ration.

SUMMARY.

1. Four hays were collected from Rawalpindi, Murree, Lahore and Amballa, and their respective feeding values determined.

2. A consideration of the daily nitrogen balances reveals the fact that only the hay from Amballa was of a maintenance standard. This hay was mostly made from "Anjan grass" (*Pennisetum Cenchroides*, Rich), and is richer in phosphates, potassium, total ash, and protein, in fact in most of the more essential ingredients of the food stuffs.

3. The grass hays from Rawalpindi, Murree and Lahore do not constitute maintenance rations when fed alone.

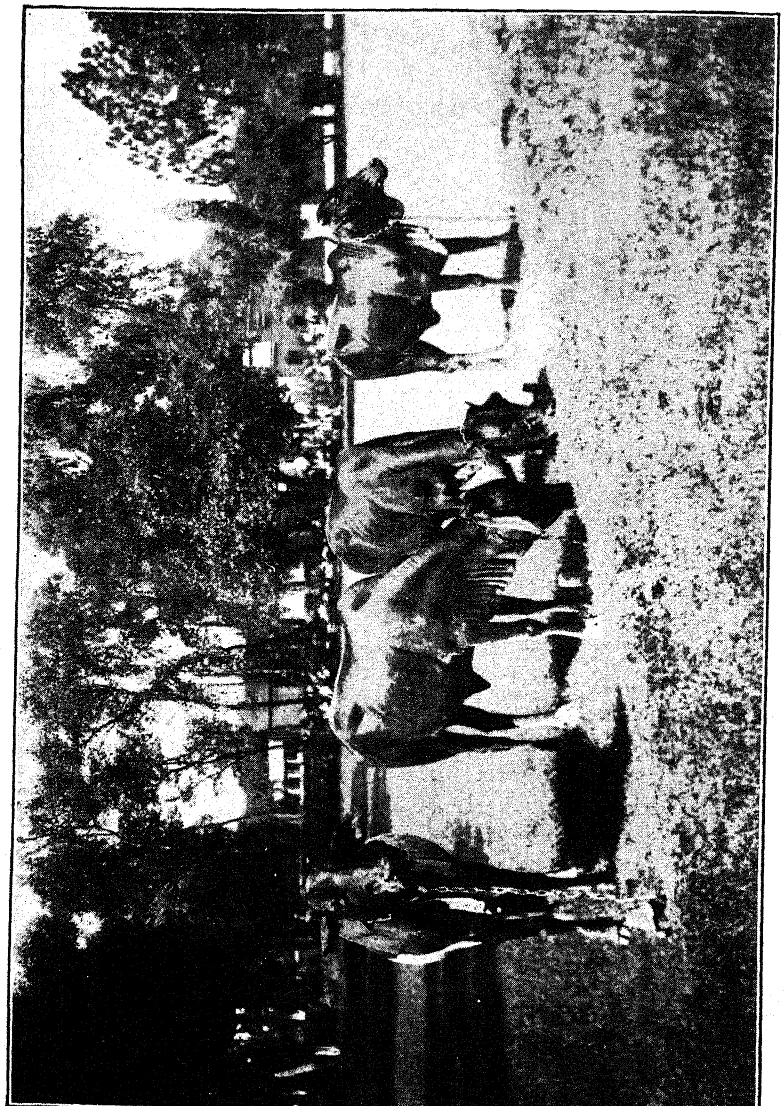
The following table summarises the data obtained, showing the amount of added bran required for animals of a certain weight when fed with the hays employed in these trials.

No. of heifer	Average of daily body weight	Hay and quantity eaten		Quantity of bran eaten per day	Daily nitrogen balance in grams
	lb.		lb.		
117	467	Amballa Hay	8·7	*Nil*	2·07
120	376	Do.	7·8	*Nil*	3·35
115	365	Rawalpindi Hay	4·9	1·5	7·05
116	490	Do.	7·6	1·5	4·73
117	419	Murree Hay	5·4	2·0	8·83
120	335	Do.	4·3	1·0	3·87
115	392	Lahore Hay	7·6	0·5	1·79
116	511	Do.	9·0	0·5	1·80

We wish, in conclusion, to acknowledge the help afforded by Lieutenant-Colonel Marriott of the Army Head Quarters (Military Grass Farms), for kindly providing us with the various grass hays, and Mr. D. P. Johnston, Professor of Agriculture, for supplying the animals ; also to Messrs. Akbar Ali and Hari Ram of the Chemical Laboratories for their assistance in the chemical analyses.

MGIPC—M—III-1-37—30-10-29—500.

PLATE I.



LEFT TO RIGHT = MONTGOMERY HEIFERS Nos. 116, 115, 117, 120.

SOME DIGESTIBILITY TRIALS ON INDIAN FEEDING STUFFS, PART V.

AMERICAN AND INDIAN COTTON SEEDS.

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In the Punjab in the year 1925-26 some one and a quarter million acres of land were under American cotton, chiefly 285 F., 289 F. and 4 F., giving a yield of roughly one hundred and twenty thousand tons of seed, while corresponding figures for Indian cotton were roughly one and a half million acres and one hundred and sixty thousand tons of seed.

The cotton seed produced represents an enormous potential source of oil and cake, the former of which could be converted into vegetable 'ghee,' while the latter would serve as a valuable feed for cattle. The general practice, however, is to feed the seed as it is without attempting to crush it, a procedure which is no doubt wasteful as cattle do not require so high a percentage of oil in the ration. *Desi* seed is the more popular seed for feeding purposes there being considerable prejudice against the use of the American varieties, especially 285 F. and 289 F., partly due to the fact that they retain a certain amount of lint after ginning, and partly due to the widespread belief that the seed causes some heating effect, although there appears to be no scientific basis for this belief. Considerable difficulty has therefore been experienced in disposing of the American seed with the exception of 4 F., which is practically naked, and this seed usually fetches a lower price than does the Indian variety. The heating effect where it occurs may be due to the high percentage of oil contained in the seed *viz.*, about 20 per cent., but *Desi* seed contains nearly as much.

In view of these prevailing prejudices it was decided to undertake carefully controlled feeding experiments with each of these varieties of seed in order to ascer-

tain what their respective values were, and to note whether the American varieties produced the ill effects which they were reputed to do.

The trials were commenced in April 1928, four heifers of the Montgomery breed designated by the numbers 115, 116, 117 and 120 being employed, whose ages and body weights were as follows :—

No. of the heifer	Average body weight in lb.	Date of birth
115	447	4th July 1925.
116	570	6th July 1925.
117	495	9th July 1925.
120	410	28th October 1925.

Plate I shows the heifers and Fig. 1 shows the details of the body weights during the course of the experiment.

Throughout the period under experiment, a non-experimental period on the particular diet under investigation was always allowed before the experimental period began, and before feeding any of the cotton seed all four animals were put on a basal ration of oat hay from the results of which the values for the cotton seeds could be computed when the combined diets were fed.

The Oat Hay.

The hay employed was made from the country variety of oats grown on the College Estate at Lyallpur in 1925, and was cut at the " milk-stage " for conversion into hay. The chemical analysis of the hay is shown in Table I and the results obtained from the trials carried out on the four animals are shown in Tables II and III, whilst the figures indicating the daily nitrogen balances when the animals were on oat hay alone are given in Table IV. All the figures obtained are positive showing that the oat hay conforms to the requirements of a maintenance ration, while the digestibility coefficients for oat hay as a whole and also for its separate constituents are all normal. It appeared from these figures that the oat hay was a suitable ration to employ as a basal ration with cotton seed for the purpose of computing values for the latter.

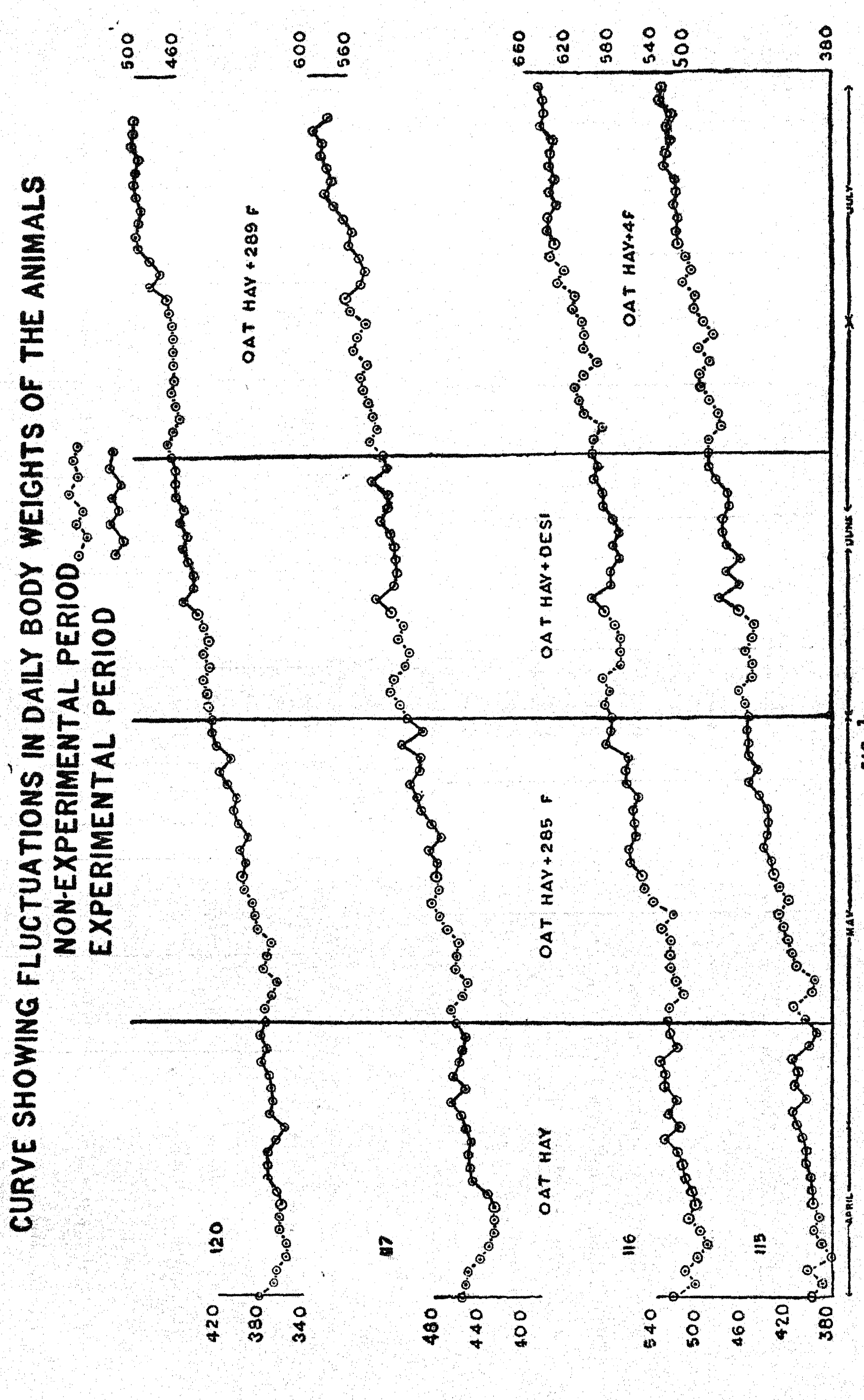
CURVE SHOWING FLUCTUATIONS IN DAILY BODY WEIGHTS OF THE ANIMALS
NON-EXPERIMENTAL PERIOD
EXPERIMENTAL PERIOD
120
117
116
115
OAT HAY
OAT HAY + 285 F
OAT HAY + DESI
OAT HAY + 289 F
OAT HAY + 4 F
APRIL
MAY
JUNE
JULY
420
380
340
480
440
400
540
500
460
420
380
500
460
600
560
660
620
580
540
500
380

FIG. 1.

TABLE I.

Chemical composition.

Name of the feed	Moisture	Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
285 F. American cotton seed	4·42	95·58	4·01	18·76	25·96	18·13	28·72
289 F. American cotton seed	6·33	93·67	4·95	18·77	26·20	18·13	25·62
4 F. American cotton seed	6·71	93·29	4·63	20·73	20·96	17·50	29·47
Desi cotton seed	6·78	93·22	4·73	17·64	21·67	14·38	34·80
Oat hay	4·00	96·00	6·94	1·81	33·98	5·00	48·27

Mineral matter in 1,000 lb. of the feed.

Name of the feed	Phosphates. P_2O_5	Calcium CaO	Sodium Na_2O	Potassium K_2O	Magnesium MgO	Manganese Mn_3O_4	Aluminium Al_2O_3	Iron Fe_2O_3	Sulphate So_4	Chlorides Cl	Insoluble residue
	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
285 F. American cotton seed	12·95	3·41	0·77	10·30	5·50	0·34	0·12	0·27	1·85	0·24	2·40
289 F. American cotton seed	12·54	3·44	0·62	9·73	5·44	0·31	0·31	0·30	1·80	0·23	3·90
4 F. American cotton seed	13·29	3·99	0·54	9·38	5·54	0·26	0·28	0·24	2·04	0·31	3·80
Desi cotton seed	12·00	4·43	0·75	10·07	5·09	0·30	0·10	0·25	1·70	0·42	1·85
Oat hay	2·94	3·30	0·86	1·94	1·59	0·36	0·38	0·40	1·70	0·20	28·90

TABLE II.

Period	Feed	No. of the heifer	(DIGESTIBILITY COEFFICIENTS OF COTTON SEED) Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract	(DIGESTIBILITY COEFFICIENTS OF COMBINED DIET) Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract
19th to 31st May 1928.	Oat hay and cotton seed (285 F.).	115	59·58	50·00	94·64	53·84	61·10	63·03	61·12	20·59	88·72	62·03	54·73	63·10
Ditto .	Ditto .	116	62·04	42·50	90·66	62·51	63·01	67·83	63·03	25·56	87·22	66·02	56·69	63·76
Ditto .	Ditto .	117	57·58	43·75	93·34	73·16	75·34	66·10	64·16	27·40	90·00	66·30	64·04	63·40
Ditto .	Ditto .	120	73·51	41·67	91·08	82·06	70·36	63·94	62·47	27·42	86·97	66·24	57·77	61·75
3th to 20th June 1928.	Oat hay and cotton seed (*Desi*).	115	59·28	..	90·56	75·38	53·49	46·16	61·06	11·84	85·50	66·30	50·00	63·28
Ditto .	Ditto .	116	54·64	..	84·89	63·07	46·51	50·97	61·59	13·18	82·18	66·50	47·47	64·68
Ditto .	Ditto .	117	54·28	..	92·44	50·76	58·12	45·19	58·41	16·45	87·12	62·23	50·00	59·31
Ditto .	Ditto .	120	67·84	..	86·78	73·84	65·12	61·54	60·40	27·40	83·81	63·54	52·32	61·27
6th to 18th July 1928.	Oat hay and cotton seed (4 F.)	115	51·07	..	90·32	49·21	64·14	34·09	59·10	8·95	86·08	61·83	55·56	61·85
Ditto .	Ditto .	116	53·00	..	85·48	26·99	56·60	26·13	57·67	7·95	83·13	61·45	51·35	61·73
2nd to 16th July 1928.	Oat hay and cotton seed (289 F.)	117	56·94	..	89·27	54·33	64·82	51·95	59·06	9·52	85·14	62·65	54·82	61·07
Ditto .	Ditto .	120	50·52	..	85·70	49·37	62·96	42·85	56·00	6·67	81·94	58·67	52·05	58·56
Oat hay.														
24th April to 8th May 1928.	Oat hay alone .	115	61·62	25·00	68·74	64·38	46·51	67·46	..	..	..	..	..	..
Ditto .	Ditto .	116	63·38	27·63	75·00	67·01	47·27	67·30	..	..	..	..	..	..
Ditto .	Ditto .	117	59·68	23·44	70·59	64·54	43·47	62·61	..	..	..	..	..	..
Ditto .	Ditto .	120	57·80	24·53	71·42	61·23	39·47	61·30	..	..	..	..	..	..

TABLE III.

Period	No. of the heifer	Average daily body weight lb.	Food eaten per day in lb.	IN COMBINED FEED				IN COTTON SEEDS		IN COTTON SEEDS		
										Per 100 lbs. of cotton seeds		
				Digestible total nutrients lb. per day	Digestible Protein lb. per day	Albuminoid Ratio 1 :	Daily nitrogen balance grams	Starch equivalents per day lb.	Protein per day lb.	Starch equivalents lb.	Protein lb.	Albuminoid Ratio 1 :
19th to 31st May 1928.	115	447	Oat Hay : 8·1 Cotton Seed (285 F.) : 3	7·08	0·52	12·8	27·03	2·13	0·33	71·02	11·00	6·1
Ditto .	116	570	Oat Hay : 10·7 Cotton Seed (285 F.) : 4	7·49	0·72	12·5	29·82	2·94	0·46	73·52	11·50	6·0
Ditto .	117	495	Oat Hay : 8·2 Cotton Seed (285 F) : 4	7·08	0·73	10·5	30·52	3·34	0·55	83·60	13·75	5·7
Ditto .	120	410	Oat Hay : 7·2 Cotton Seed (285 F) : 3	5·21	0·52	11·9	20·77	2·51	0·38	83·67	12·67	6·2
8th to 20th June 1928.	115	477	Oat Hay : 8·9 Cotton Seed (Desi) : 3	5·77	0·44	16·3	17·57	2·11	0·23	70·29	7·67	9·0
Ditto .	116	587	Oat Hay : 11·1 Cotton Seed (Desi) : 3	6·66	0·47	18·0	17·97	2·00	0·20	66·70	6·67	9·9
Ditto .	117	526	Oat Hay : 9 4 Cotton Seed (Desi): 3	5·61	0·45	15·8	18·14	1·99	0·25	66·23	8·33	7·7

Ditto	[illegible]	453	Oat Hay: 8·5 Cotton Seed (Desi): 3	5·40	0·45	14·9	20·00	2·25	0·28	75·07	9·33	7·8
9th to 18th July 1928.	115	526	Oat Hay: 9·1 Cotton Seed (4 F.): 3	5·78	0·55	13·0	24·58	2·03	0·34	67·76	11·33	5·6
Ditto	116	638	Oat Hay: 11·5 Cotton Seed (4 F.): 3	6·55	0·57	14·6	22·51	1·74	0·30	57·93	10·00	5·4
2nd to 16th July 1928.	117	569	Oat Hay: 9·9 Cotton Seed (289 F.): 3	5·96	0·57	13·1	21·04	2·12	0·35	70·80	11·67	5·7
Ditto	120	491	Oat Hay: 8·7 Cotton Seed (289 F.): 3	5·17	0·51	12·7	21·90	1·97	0·34	65·70	11·33	5·4
Oat hay alone.												
24th April 1928 to 8th May 1928.	115	405	Oat Hay alone: 8·6	..	..	..	4·86	3·42	0·20	39·72	2·33	24·7
Ditto	116	523	Oat Hay alone: 10·9	..	..	..	5·98	4·45	0·26	40·81	2·39	24·5
Ditto	117	453	Oat Hay alone: 9·2	..	..	..	3·96	3·44	0·20	37·34	2·17	25·4
Ditto	120	370	Oat Hay alone: 7·6	..	..	..	2·90	2·68	0·15	35·31	1·97	27·1

TABLE IV.

Showing details of daily nitrogen balance in grams.

Period	No. of the heifer	Feed	Intake		Outgo			Total intake	Total Outgo	Balance
			Hay	Concentrates	Dung	Urine	Brushings			
19th to 31st May 1928	115	Oat Hay and 285 F. Cotton Seed.	29·40	39·48	23·87	17·98	Traces	68·88	41·85	27·03
Ditto ditto	116	Ditto ditto	38·84	52·64	39·52	22·14	Do.	91·48	61·66	29·82
Ditto ditto	117	Ditto ditto	29·77	52·64	29·84	22·05	Do.	82·41	51·89	30·52
Ditto ditto	120	Ditto ditto	26·14	39·48	27·33	17·52	Do.	65·62	44·85	20·77
8th to 20th June 1928	115	Oat Hay and Desi Cotton Seed.	32·31	31·31	32·00	14·05	Do.	63·62	46·05	17·57
Ditto ditto	116	Ditto ditto	40·29	31·31	37·35	16·28	Do.	71·60	53·63	17·97
Ditto ditto	117	Ditto ditto	34·13	31·31	32·74	14·56	Do.	65·44	47·30	18·14
Ditto ditto	120	Ditto ditto	30·86	31·31	29·99	12·18	Do.	62·17	42·17	20·00
6th to 18th July 1928	115	Oat Hay and 4 F. Cotton Seed.	33·04	38·10	31·84	14·72	Do.	71·14	46·56	24·58
Ditto ditto	116	Ditto ditto	41·74	38·10	38·96	18·37	Do.	79·84	57·33	22·51
2nd to 16th July 1928	117	Oat Hay and 289 F. Cotton Seed.	35·94	39·48	34·17	20·21	..	75·42	54·38	21·04
Ditto ditto	120	Ditto ditto	31·58	39·48	34·17	14·99	..	71·06	49·16	21·90

Oat Hay.

Period	No. of the heifer	Feed	Hay	Concentrates	Dung	Urine	Brushings	Total intake	Total Outgo	Balance
24th April 1928 to 8th May 1928.	115	Oat Hay alone	31·22	..	16·77	9·59	Traces	31·22	26·36	4·86
Ditto ditto	116	Ditto	39·56	..	21·10	12·48	Do.	39·56	33·58	5·98
Ditto ditto	117	Ditto	33·38	..	18·67	10·75	Do.	33·38	29·42	3·96
Ditto ditto	120	Ditto	27·57	..	16·33	8·34	Do.	27·57	24·67	2·90

During the course of the trials the usual procedure and precautions have been observed which have been fully described in earlier papers* of this series on digestibility trials carried out at this Institute.

The chemical analyses of the various cotton seeds used are shown in Table I, and the only distinguishing features which these figures reveal are that the American cotton seeds used were richer in fat and protein than the *desi* variety and that the American varieties 285 F. and 289 F. contain a higher percentage of crude fibre.

On the other hand, the oat hay was richer in total ash but much lower in phosphates, potassium and magnesium than the cotton seeds.

The cotton seed was fed twice a day, in the morning and evening, and was always soaked in water for twelve hours prior to being fed so as to soften the hard outer integument. The seed to be fed each day was also carefully weighed and stored in labelled cloth bags at the beginning of each experimental period after thorough mixing of the bulk supply when a sample was taken also for the chemical analysis. This procedure also tended to minimise error likely to creep in from daily weighings.

The actual amounts of cotton seed as shown in column 4 of Table III were fed in buckets which kept the seed separate from the oat hay which was fed *ad lib.* A sufficient quantity of the hay for each day for each animal was also weighed out into labelled gunny bags and the daily residues collected in separate bags and again weighed at the end of each period. The slight variations in the quantity of cotton seed fed were made in order to see whether such variations would have any effect on the digestibility figures obtained.

It will be noted that the amount of hay eaten by the animals is roughly proportional to their body weights (Col. 4, Table III).

Table III also shows that the daily nitrogen balances expressed in grams are all distinctly positive, and that the albuminoid ratio is within limits which are generally considered suitable.

A glance at the body weight curve confirms the efficiency of the cotton seeds as a concentrate if an increase in weight be taken as a criterion of efficiency.

Table II shows the digestibility figures obtained from the combined feed (actual) and the cotton seed, the latter being deduced by calculation based on the previous trials when oat hay alone was fed as a basal ration. Table VI shows the quantities of the various nutrients digested per day for each feed.

A survey of these figures does not reveal any pronounced difference between the values of the *Desi* and the American variety 285 F., but certain distinguishing features are revealed when we come to consider the digestible starch equivalents and digestible protein per 100 lb. of the cotton seed, and also the albuminoid ratio as shown in Table V. American 285 F. is then seen to be superior to the *Desi* variety in every respect.

* *Mem. Dept. Agri. India, Chem. Ser.*, Vol. VII, No. 4, Sept. 1924; *Pusa Agric. Research Inst Bulletin* No. 158 of 1925; *Mem. Dept. Agri. India, Chem. Ser.*, Vol. IX, No. 3, April 1927; and *Mem. Dept. Agri. India, Chem. Ser.*, Vol. IX, No. 7, April 1928.

TABLE V.

Feed	Per 100 lb. of cotton seed		Albuminoid ratio 1 :
	Starch equivalents	Protein	
	lb.	lb.	
285 F. American cotton seed . . .	77·95	12·23	6·0
289 F. American cotton seed . . .	68·25	11·50	5·6
4 F. American cotton seed . . .	62·85	10·67	5·5
Desi cotton seed	69·57	8·00	8·6
Oat hay.			
Oat hay	38·30	2·22	25·4

NOTE.—The above figures have been obtained from the digestibility experiments.

TABLE VI.

Showing nutrients digested per day in the combined feed.

Period	Feed	No. of the heifer	Nutrients digested per day in the combined feed					
			Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract
19th to 31st May 1928.	Oat hay and 285 F. Cotton seed.	115	6·51	0·14	0·63	2·19	0·52	3·01
Ditto .	Ditto .	116	8·88	0·23	0·82	3·09	0·72	4·03
Ditto .	Ditto .	117	7·50	0·20	0·81	2·54	0·73	3·24
Ditto .	Ditto .	120	6·11	0·17	0·60	2·14	0·52	2·68
8th to 20th June 1928.	Oat hay and Desi cotton seed.	115	6·93	0·09	0·59	2·44	0·44	3·38
Ditto .	Ditto .	116	8·29	0·12	0·60	2·94	0·47	4·14
Ditto .	Ditto .	117	6·91	0·13	0·61	2·39	0·45	3·31
Ditto .	Ditto .	120	6·62	0·20	0·57	2·25	0·45	3·15
6th to 18th July 1928.	Oat hay and 4 F. Cotton Seed.	115	6·82	0·03	0·68	2·30	0·55	3·26
Ditto .	Ditto .	116	7·98	0·03	0·69	2·79	0·57	3·97
2nd to 16th July 1928.	Oat hay and 289 F. Cotton seed.	117	7·27	0·08	0·63	2·60	0·57	3·39
Ditto .	Ditto .	120	6·25	0·05	0·59	2·20	0·51	2·91
24th April 1928 to 8th May 1928.	Oat hay alone .	115	5·09	0·09	0·11	1·88	0·20	2·80
Ditto .	Ditto .	116	6·63	0·21	0·15	2·48	0·26	3·54
Ditto .	Ditto .	117	5·27	0·15	0·12	2·02	0·20	2·78
Ditto .	Ditto .	120	4·22	0·13	0·10	1·58	0·15	2·25

This experiment on its conclusion was followed by one in which American varieties 4 F. and 289 F. were employed, the trial lasting from June 20th to July 18th. Two animals were used in each case and the method of procedure exactly as followed earlier.

The complete data is shown in Tables I to VI along with the earlier figures, and in each case the American proves to be superior to the *Desi*, 285 F. being the best of them all, showing a high figure for protein and starch equivalents per hundred lb. of feed and also a satisfactory albuminoid ratio.

Summary.

1. The Chemical analyses of American cotton seeds 285 F., 289 F. and 4 F. (*Gossypium hirsutum*) show them to be richer in fat and protein than *Desi* cotton seeds. (*Gossypium indicum*).

2. The digestibility coefficients of the various cotton seeds do not present sufficiently marked differences to warrant any definite distinction being made in their nutritive values but the digestible starch equivalent and digestible protein per 100 lb. of cotton seeds and also the albuminoid ratio reveal the superior value of 285 F. American cotton seed and to a lesser degree that of 289 F. and 4 F. American cotton seeds. Generally the American cotton seeds sell at a cheaper rate than *Desi* cotton seeds, therefore it pays to feed them in preference to *Desi* cotton seeds, the former being more nutritious than the latter.

3. In spite of the warm season during which the experiments were carried on, no harmful effects whatsoever were noticed, nor were the animals ever choked as a result of adhering lint.

4. It has been suggested above that an oil content as high as that shown by the cotton seed employed is unnecessary for these animals and that perhaps a greater utilisation of the feed would be made if oil seed cake instead of oil seed were fed. It is hoped when opportunity offers to obtain definite experimental evidence on this point.

We wish, in conclusion, to express our thanks to Mr. D. P. Johnston, Professor of Agriculture, for supplying the animals and to Messrs. Akbar Ali and Hari Ram for their assistance in the chemical analyses.

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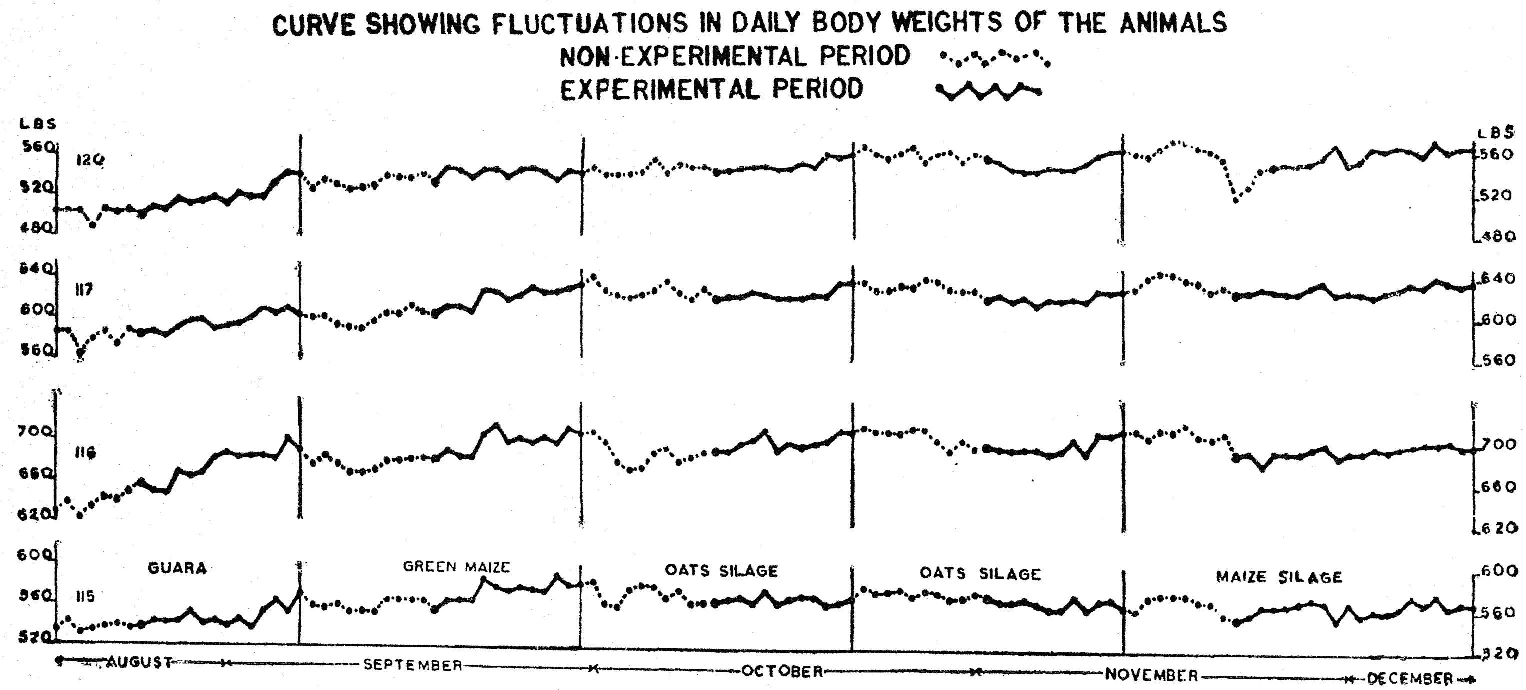
CURVE SHOWING FLUCTUATIONS IN DAILY BODY WEIGHTS OF THE ANIMALS
NON-EXPERIMENTAL PERIOD
EXPERIMENTAL PERIOD
LBS
560
520
480
120
640
600
560
117
700
660
620
116
600
560
520
115
GUARA
GREEN MAIZE
OATS SILAGE
OATS SILAGE
MAIZE SILAGE
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

Fig. 1.

SOME DIGESTIBILITY TRIALS ON INDIAN FEEDING STUFFS, PART VI.

GREEN FODDERS AND THEIR SILAGE.

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In this paper an account is given of digestibility trials carried out at the Lyallpur Agricultural Research Institute on the following green fodders and their silage in order to study the effect of ensiloing on the digestibility of the fodders used :—green oats (*Avena sativa*), oat silage, green maize (*Zea Mays*) and maize silage.

For the sake of comparison, some data obtained from oat hay during different periods and from green guara (*Cyamopsis psoralioides*), is also given.

The trials under discussion were started in June 1925 and carried on till the end of 1928 ; the details of the periods, the fodders and the animals employed are given in Table I.

The general method of conducting the trials was similar to that described in earlier papers of this series and need not be repeated, but in no case were unsatisfactory effects noticeable in the animals under trial, which received regular daily exercise and the physiological condition of which remained good as may be seen from the weight curve (Fig. I) and the daily nitrogen balances obtained (Tables IV and VIII).

SILAGE PITS.

Three silage pits were used, two specially designed for these experiments with oat silage, the third being an ordinary farm silo pit filled with maize silage. The two

oat silage pits were 6 feet deep with 8 feet diameter and were filled in the last week of March 1926, and opened in the first week of October 1928, after a period of about thirty months, when feeding trials were commenced with oat silage. The green fodder was cut to about half-inch length with the power chaff-cutter at the time of filling in these pits.

In pit I four sample bags were placed at depths given below :—

Bag I. 2 feet from the top.

Bags II and III. Between third and fourth foot from the top.

Bag IV. Between fourth and fifth foot from the top.

These bags were filled with the green fodder under investigation at the time of filling in the silo pit and were taken out as the feeding proceeded. In the second pit for purposes of analysis three bags were placed at various depths as shown below :—

Bag I. 2 feet from the top.

Bag II. In the middle of the pit.

Bag III. Between fourth and fifth foot.

Two minimum and maximum thermometers were also placed under bags II and III in pit I, and one minimum and maximum thermometer was placed under bag I in the second pit. The maximum temperatures recorded by these thermometers range from 98° to 101°F. in case of pit I.

These temperatures show a maximum point suitable for the production of the type of silage known as " Acid brown silage " which possessed a rich fruity smell and was brown in colour and highly relished by the animals.

In the second pit the maximum temperature recorded at a depth of 2 feet from the top was 95°F. It was noticed that the silage in the upper part of this pit was similar in colour to that obtained from the first pit, *viz.*, a rich brown, but the lower layers were of a greener colour and resembled in other respects that type of silage known as " fruity green silage." An analysis of these two types of silage, however, for various organic acids and volatile bases do not reveal any striking differences in chemical composition (Table VII).

The silage in these pits when used was, therefore, about 30 months old and had been carefully protected from rain and weather by a layer of earth over the top shaped in the form of a mound. The details of making the silo pit and filling, etc., are given in Bulletin No. 158 of the Agricultural Research Institute, Pusa.

Table II shows the complete chemical analyses of the various fodders employed.

The oat hay which was employed in the period shown in Table I was grown and stacked in 1925.

The maize silage fed was grown and ensilaged in September 1927, and fed at the end of 1928, but the stage at which the fodder was gathered was rather advanced as

some of the cobs had started to form ; the result of this was that the silage produced was somewhat dry, a feature not uncommon to maize silage.

The only special features in the chemical analyses to which attention may be drawn are, firstly, that the fat content of the silage in the two oat silage pits was very different although repeated analyses were made to check these figures ; secondly, that there was the high protein content of the green guara, with its consequent reflection in the albuminoid ratio of this fodder, which must, however, be interpreted in the light of its high moisture content. The green guara was fed at an early stage of growth before any inflorescence made appearance. (It was sown on 11th June 1928).

In Tables IV and IVA full details are given of the feeding standards obtained for all of these fodders, and of the animals employed, also the details of the digestibility coefficients of the fodders and their chemical ingredients, whilst Table V summarises these data as averages.

From Table IVA certain conspicuous features are revealed, for example, we notice that the digestibility coefficient of the fat in the silage from pit I is lower than the digestibility figures obtained from the fresh green oats, but in the case of the silage from pit II, whose fat content as seen from Table II was double that of the silage from pit I, the digestibility figures are considerably higher. No explanation of this has been found because even though the fat content was high, it is difficult to see why its digestibility should have followed suit and the reason for the different fat content in the two pits is also difficult of explanation, as the fodder employed in both cases was the same, the pits having been filled on two consecutive dates, *i.e.*, 23rd and 24th March 1926.

Looking up the digestibility figures for fat on the oat hay ration, we notice that the first four which were obtained from fully grown cows are lower than those obtained from the other six animals which were heifers.

In the case of the digestibility coefficients of the protein, we also notice that the figures are somewhat lower for the oat silage than for the fresh green oats. The figures for the protein of the oat hay are almost similar in the case of both heifers and fully grown cows.

Turning to the column of daily nitrogen balances (Table IV), we notice that they all are highly positive, the lowest figures being obtained from the oat hay ration, while the highest figures were obtained with green guara, which gave a very narrow albuminoid ratio as stated above.

Table VI shows the starch equivalents and digestible protein per 100 lb. of fodder and the albuminoid ratios in the same table, the same data has been computed on a dry matter basis for the sake of comparison.

A conspicuous feature of the table is the high starch equivalents and protein content of the oat hay as contrasted with a corresponding high protein figure but a very low starch equivalent for the green guara. These facts which must be interpreted in terms of moisture content are shown in the other half of the same table

where they have been computed in terms of dry matter. The oat hay and the green guara are of equal value in starch equivalents per 100 lb. of fodder, but the vast superiority of the green guara over the oat hay is reflected in the figure for digestible protein, which is again reflected in an exceedingly narrow albuminoid ratio for green guara as contrasted with a very wide ratio for oat hay. We also notice that the starch equivalent in terms of dry matter in the case of oats has diminished after siloing, and the protein as such has also diminished by nearly 40 per cent. and at the same time the albuminoid ratio has widened as would be expected.

Table VII shows the data which were obtained for the various organic acids and bases in the green and siloed fodders. An investigation of these features is valuable in throwing light on the chemical changes which may have occurred during the process of ensilage, and also helps one to interpret the nature of the silage which has been produced in each case, and which will vary according to the condition of temperature attained, and the condition of the material at the time of ensilage. For example, it is important in packing the silo pits that the material shall not be in too moist a condition which would conduce to a more solid consistency in pit, and consequently prevent proper aeration by the exclusion of air ; nor on the other hand should it be too dry.

When silage is packed in a too sappy condition, the tendency is for an acid and unpalatable silage to be produced owing to interference with the proper condition essential for the production of good silage.

A perusal of Table VII shows the increase of the volatile organic acids, amino acids, and the volatile bases during the process of ensilage.

It will be noted that the amino acids, which reflect protein decomposition, increase *pari passu* with the volatile organic acids, but, as shown in Table IVA, the digestibility of the residual protein has somewhat decreased. The non-volatile organic acids have decreased in each case.

There is not sufficient difference in the figures from the brown and green silage in pit II, to warrant an assumption that any pronounced diffierence in chemical changes have occurred in these portions (Table VII).

These figures for volatile and non-volatile organic acids are in agreement with those found by [1] Annett but are the reverse of what Amos [2] and Woodman found. They found that non-volatile acids were in excess of the volatile acids, while our figures show the reverse, with the exception of the results obtained in the case of bag IV in pit I.

Another feature brought out in our trials is that the loss of dry matter during the course of ensilage is generally over 20 per cent., whereas Amos and Woodman obtained figures from 7-16 per cent. only (Table III).

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[1] Annett, Harold E., and Aiyer, A. R. P. Silage Experiments at Nagpur. *Memoirs of the Department of Agriculture in India, Chemical Series*, Vol. VIII, No. 10, April 1928.

[2] Amos and Woodman, *Journal of Agri. Science*, Vol. XII, 1922, p. 337.

It has been shown that under the process of storing oat hay in stacks there is a progressive diminution in the protein content from 6·80 to 5·21 per cent. in the course of about three years. A similar small decrease is shown in the protein content of oats after being siloed for about 30 months.

Summary.

Feeding trials conducted on green oats, oat silage, oat hay, green maize, maize silage, and green guara, fed *ad. lib.*, reveal these fodders to be effective maintenance rations able to keep the animals in health with high positive daily nitrogen balance.

2. The relative feeding values in terms of starch equivalent, protein, and albuminoid ratio, have also been determined (Table VI).

3. For purposes of preserving fodder for times of scarcity and famine, these trials indicate that both in terms of composition and digestibility it is better to ensilage the green fodder rather than convert it into hay. The ensilaged material also proves more attractive to the animals than does the hay.

In conclusion, the authors wish to express their appreciation of the valuable assistance rendered by Mr. Johnston, Professor of Agriculture, Punjab, in providing the animals and fodders, and to Messrs. M. Akbar Ali and Hari Ram of the chemical section for their assistance in carrying out the analyses.

TABLE I.

Showing the periods, fodders and the animals employed in the digestibility experiments.

Period	Fodder	Animal (Name or Number)
4th to 15th June 1925	Oat hay .	Cow : Lundi.
Ditto	Do. .	,, : Moni.
28th October 1925 to 16th November 1925 . .	Do. .	,, : Lucy.
Ditto	Do. .	,, : Alice.
25th January 1926 to 13th February 1926 . .	Green oats .	Heifer : Bimla.
Ditto	Do. .	,, : Ursula.

TABLE I—*contd.*

Showing the periods, fodders and the animals employed in the digestibility experiments—contd.

Period	Fodder	Animal (Name or Number)
19th to 25th April 1927	Oat hay	Heifer : 104.
Ditto	Do.	„ : 105.
24th April 1928 to 8th May 1928	Do.	„ : 115.
Ditto	Do.	„ : 116.
Ditto	Do.	„ : 117.
Ditto	Do.	„ : 120.
24th August 1928 to 6th September 1928	Green guara	„ : 115.
Ditto	Do.	„ : 116.
17th to 29th September 1928	Green maize	„ : 115.
Ditto	Do.	„ : 116.
Ditto	Do.	„ : 117.
Ditto	Do.	„ : 120.
10th to 21st October 1928	Oat silage (Pit I)	„ : 115.
Ditto	Do.	„ : 116.
Ditto	Do.	„ : 117.
Ditto	Do.	„ : 120.
1st to 12th November 1928	Do. (Pit II).	„ : 115.
Ditto	Do.	„ : 116.
Ditto	Do.	„ : 117.
Ditto	Do.	„ : 120.
21st November 1928 to 8th December 1928	Maize silage	„ : 115.
Ditto	Do.	„ : 116.
Ditto	Do.	„ : 117.
Ditto	Do.	„ : 120.

TABLE II.

Chemical analyses of the feed.

Period	Name of the feed	PER 100 GRAMS OF THE FEED AS SUCH							PER 100 GRAMS DRY MATTER CONTAINED IN THE FEED				
		Moisture	Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract	Ash	Fat	Fibre	Protein	Nitrogen free extract
25th January 1926 to 13th February 1926.	Green Oats .	83·77	16·23	1·75	0·36	4·32	1·61	8·19	10·78	2·22	26·62	9·92	50·46
19th to 21st October 1928.	Oat Silage (I Pit).	72·42	27·58	2·65	0·44	11·26	2·02	11·21	9·61	1·60	40·82	7·32	40·65
1st to 12th November 1928.	Oat Silage (II Pit).	72·11	27·89	2·64	0·83	11·09	2·27	11·06	9·47	2·98	39·76	8·14	39·65
4th to 15th June 1925.	Oat Hay .	2·20	97·80	8·26	1·67	35·91	6·65	45·31	8·45	1·71	36·71	6·80	46·33
28th October 1925 to 16th November 1925.	Do. . .	10·53	89·47	8·33	1·30	30·70	5·75	43·39	9·31	1·45	34·31	6·43	48·50
19th to 25th April 1927.	Do. . .	3·36	96·64	6·53	1·84	33·94	5·69	48·64	6·76	1·90	35·12	5·89	50·33
24th April 1928 to 8th May 1928.	Do. . .	4·00	96·00	6·94	1·81	33·98	5·00	48·27	7·23	1·89	35·39	5·21	50·28
17th to 29th September 1928.	Green Maize .	79·52	20·48	1·84	0·30	5·27	1·56	11·51	8·98	1·47	25·73	7·62	56·20
21st November 1928 to 8th December 1928.	Maize Silage .	74·48	25·52	2·89	0·28	6·27	2·02	14·06	11·33	1·10	24·57	7·92	55·08
24th August 1928 to 6th September 1928.	Green guara .	80·82	19·18	3·27	0·37	4·35	3·06	8·13	17·05	1·93	22·68	15·95	42·39

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TABLE III.

Showing amounts of constituents of green oats and oat silage contained in the bags.

—		Green oats	Silo No. I (Oat silage)				Silo No. II (Oat silage)						Silo III
			Bag I	Bag II	Bag III	Bag IV	Green oats	Bag I	Bag II	Bag III	Brown silage	Green silage	Maize silage
Moisture per cent.		69·85	72·17	71·75	73·70	72·05	72·20	73·72	71·62	72·00	71·10	71·30	74·48
Dry matter per cent.		30·15	27·83	28·25	26·30	27·95	27·80	26·28	28·38	28·00	28·90	28·70	25·52
„ „ as ensiled (Grams).		..	359·1	2822·0	2659·0	2651·0	..	2238·0	1986·0	..	..	..	..
„ „ after ensiling (Grams).		..	264·9	2210·0	1909·0	1934·0	..	1788·0	1641·0	..	..	..	..
Loss of dry matter		..	94·2	612·0	750·0	717·0	..	450·0	345·0	..	..	..	..
Per cent. loss of dry matter.		..	26·23	21·69	28·21	27·04	..	20·78	17·37	..	..	..	..
Ash per cent.	Per cent. on feed as such.	2·90	2·77	2·79	2·60	2·51	3·30	2·78	2·42	2·87	2·49	2·33	2·89
Fat per cent.		0·68	0·58	0·25	0·70	0·24	0·62	0·97	0·97	0·63	0·76	0·53	0·28
Fibre per cent.		12·00	11·48	10·88	11·53	11·14	12·50	10·34	11·05	10·85	12·12	12·63	6·27
Crude Protein per cent.		2·01	1·81	1·81	2·19	2·25	2·22	2·00	..	2·38	2·44	2·06	2·02
True Protein per cent.		1·54	0·81	0·81	0·81	1·00	1·69	1·06	..	0·94	1·13	0·94	..
" Amides "		0·47	1·00	1·00	1·38	1·25	0·53	0·94	..	1·44	1·31	1·12	..
Nitrogen free extract per cent.		12·56	11·19	12·52	9·28	11·81	9·16	10·19	..	11·27	11·09	11·15	14·06

TABLE IV.

Dietary Standards.

Period	No. of heifer or name of cow.	Average daily body weight	Food eaten per day	(Per 100 lbs. of food) Starch equivalents	(Per 100 lbs. of food) Protein	Albuminoid ratio	Daily nitrogen balance Grams	Fed per day Starch equivalents	Fed per day Protein
		lb.	lb.		lb.	1 :			lb.
GREEN OATS.									
25th January 1926 to 13th February 1926.	Bimla	399	45·0	8·75	1·13	8·6	25·97	3·94	0·53
Ditto	Ursula	524	45·0	8·70	1·16	8·8	20·29	3·91	0·52
OAT SILAGE.									
10th to 21st October, 1928	115	570	26·8	11·88	0·93	17·4	2·53	3·18	0·25
Ditto	116	694	37·0	12·37	1·11	14·9	8·72	4·58	0·41
Ditto (Pit I)	117	626	35·7	11·29	1·09	15·4	7·56	4·03	0·36
Ditto	120	551	32·5	11·38	1·02	15·4	7·06	3·70	0·33
1st to 12th November 1928.	115	570	23·6	12·64	1·19	14·1	3·73	2·98	0·28
Ditto	116	702	34·5	13·27	1·33	15·1	13·90	4·58	0·46
Ditto (Pit II)	117	628	28·1	18·62	1·18	13·2	9·35	5·23	0·33
Ditto	120	557	27·3	12·43	1·28	12·8	11·92	3·39	0·35
OAT HAY.									
4th to 15th June 1925	Lundi	781	15·6	38·14	3·65	15·2	..	5·95	0·57
Ditto	Moni	845	17·8	39·95	3·83	14·9	..	7·09	0·68
28th October 1925 to 16th November 1925.	Lucy	861	17·1	31·35	2·34	20·1	6·35	5·36	0·40
Ditto	Alice	572	11·8	31·87	2·71	17·4	9·52	3·76	0·32

TABLE IV—*contd.*

Dietary Standards—contd.

Period	No. of heifer or name of cow.	Average daily body weight	Food eaten per day	(Per 100 lbs. of food) Starch equivalents	(Per 100 lbs. of food) Protein	Albuminoid ratio	Daily nitrogen balance Grams	Fed per day Starch equivalents	Fed per day Protein
		lb.	lb.		lb.	1 :			lb.
			OAT HAY—*contd.*						
19th to 25th April 1927	104	484	9·3	43·12	2·37	25·7	2·19	4·01	0·22
Ditto	105	429	7·3	41·30	3·29	18·0	7·91	3·02	0·24
24th April 1928 to 8th May 1928	115	405	8·6	39·72	2·33	24·7	4·86	3·42	0·20
Ditto	116	523	10·9	40·81	2·39	24·5	5·98	4·45	0·26
Ditto	117	453	9·2	37·34	2·17	25·4	3·96	3·44	0·20
Ditto	120	370	7·6	35·31	1·97	27·1	2·90	2·68	0·15
			GREEN MAIZE.						
17th to 29th September 1928	115	568	54·8	11·76	0·93	13·6	14·30	6·45	0·51
Ditto	116	689	66·6	11·77	0·93	13·6	18·17	7·84	0·62
Ditto	117	611	57·8	11·95	0·97	11·3	14·67	6·90	0·56
Ditto	120	538	63·4	12·59	1·01	13·3	24·00	7·98	0·64
			MAIZE SILAGE.						
21st November 1928 to 8th December 1928.	115	562	29·7	14·01	0·91	16·8	8·17	4·16	0·27
Ditto	116	705	38·8	13·42	0·83	17·9	9·82	5·21	0·32
Ditto	117	629	31·9	13·55	0·88	16·9	8·48	4·32	0·28
Ditto	120	556	32·6	12·98	0·86	16·7	10·03	4·22	0·28
			GREEN GUARA.						
24th August 1928 to 6th September 1928.	115	544	50·7	8·27	2·39	3·1	23·40	4·19	1·21
Ditto	116	657	74·5	7·95	2·35	3·0	32·69	5·93	1·75

TABLE IV-A.

Digestibility factors.

Period	No. of heifer or name of cow	Average daily body weight	Food eaten per day	Digestibility coefficients: Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract	Nutrients digested per day: Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract
		lb.	lb.							lb.	lb.	lb.	lb.	lb.	lb.
						GREEN OATS.									
25th January 1926 to 13th February 1926.	Bimla	399	45·0	74·40	56·97	56·25	74·23	72·23	79·44	5·43	0·45	0·09	1·44	0·53	2·93
Ditto	Ursula	524	45·0	75·22	64·57	43·75	78·37	71·24	78·06	5·49	0·51	0·07	1·52	0·52	2·88
						OAT SILAGE.									
10th to 21st October 1928.	115	570	26·8	64·40	33·80	33·33	78·48	46·29	62·46	4·76	0·24	0·04	2·37	0·25	1·88
Ditto	116	694	37·0	66·60	34·69	31·25	79·37	54·67	64·82	6·80	0·34	0·05	3·31	0·41	2·69
Ditto (Pit I)	117	626	35·7	62·84	36·84	37·50	73·12	50·00	61·75	6·19	0·35	0·06	2·94	0·36	2·47
Ditto	120	551	32·5	63·39	38·37	35·72	74·86	50·00	60·98	5·68	0·33	0·05	2·74	0·33	2·22
1st to 12th November 1928.	115	570	23·6	63·37	19·35	60·00	78·62	51·85	61·30	4·17	0·12	0·12	2·06	0·28	1·60
Ditto	116	702	34·5	66·74	31·87	65·52	78·84	58·97	64·65	6·42	0·29	0·19	3·02	0·46	2·47
Ditto (Pit II)	117	628	28·1	59·69	20·27	56·52	74·36	51·56	56·27	4·68	0·15	0·13	2·32	0·33	1·75
Ditto	120	557	27·3	63·86	31·94	60·86	77·55	56·45	59·60	4·86	0·23	0·14	2·35	0·35	1·80
						OAT HAY.									
4th to 15th June 1925.	Lundi	781	15·6	62·32	34·11	50·00	69·11	54·81	63·81	9·51	0·44	0·13	3·87	0·57	4·51
Ditto	Moni	845	17·8	64·46	37·42	50·00	70·96	57·63	65·80	11·19	0·55	0·15	4·52	0·68	5·29
28th October 1925 to 16th November 1925.	Lucy	861	17·1	56·74	26·77	50·00	63·03	40·80	60·38	8·68	0·38	0·11	3·31	0·40	4·48
Ditto	Alice	572	11·8	57·68	29·59	53·34	61·86	47·05	61·33	6·09	0·29	0·08	2·24	0·32	3·14
19th to 25th April 1927.	104	484	9·3	64·52	17·17	76·46	67·71	41·51	71·00	5·80	0·10	0·13	2·14	0·22	3·21
Ditto	105	429	7·3	64·73	31·25	69·22	67·74	57·13	68·18	4·57	0·15	0·09	1·68	0·24	2·42

TABLE IV-A—*contd.*

Digestibility factors—contd.

Period	No. of heifer or name of cow	Average daily body weight	Food eaten per day	Digestibility coefficients						Nutrients digested per day					
				Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract	Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract
		lb.	lb.							lb.	lb.	lb.	lb.	lb.	lb.
						OAT HAY—*contd.*									
24th April 1928 to 8th May 1928.	115	405	8·6	61·62	25·00	68·74	64·38	46·51	67·46	5·09	0·20	0·11	1·88	0·20	2·80
Ditto .	116	523	10·9	63·38	27·63	75·00	67·01	47·27	67·30	6·63	0·21	0·15	2·48	0·26	3·54
Ditto .	117	453	9·2	59·68	23·44	70·59	64·54	43·47	62·61	5·27	0·15	0·12	2·02	0·20	2·78
Ditto .	120	370	7·6	57·80	24·53	71·42	61·23	39·47	61·30	4·22	0·13	0·10	1·58	0·15	2·25
						GREEN MAIZE.									
17th to 29th September 1928.	115	568	54·8	68·58	33·66	56·25	68·16	59·30	75·75	7·70	0·34	0·09	1·97	0·51	4·78
Ditto .	116	689	66·6	68·56	34·96	65·00	68·66	59·62	75·10	9·35	0·43	0·13	2·41	0·62	5·76
Ditto .	117	611	57·8	69·26	33·96	70·58	68·85	62·22	75·93	8·20	0·36	0·12	2·10	0·50	5·05
Ditto .	120	538	63·4	73·20	43·59	68·42	73·34	64·64	79·18	9·51	0·51	0·13	2·45	0·64	5·78
						MAIZE SILAGE.									
21st November 1928 to 8th December 1928.	115	562	29·7	65·30	22·09	50·00	73·64	45·00	73·68	4·95	0·19	0·04	1·37	0·27	3·08
Ditto .	116	705	38·8	62·93	23·21	63·64	68·31	41·03	71·80	6·23	0·26	0·07	1·66	0·32	3·92
Ditto .	117	629	31·9	63·50	21·74	44·44	69·50	43·75	72·60	5·17	0·20	0·04	1·39	0·28	3·26
Ditto .	120	556	32·6	60·45	23·83	55·55	65·20	42·42	70·30	5·03	0·23	0·05	1·33	0·28	3·22
						GREEN GUARA.									
24th August 1928 to 6th September 1928.	115	544	50·7	57·61	47·59	42·11	28·96	78·07	69·89	5·60	0·79	0·08	0·64	1·21	2·88
Ditto .	116	657	74·5	56·76	52·10	35·72	23·15	76·74	70·12	8·11	1·27	0·10	0·75	1·75	4·25

TABLE V.

Average of digestibility coefficients.

Period	Name of the feed	Dry matter	Ash	Fat	Fibre	Protein	Nitrogen free extract
25th January 1926 to 13th February 1926	Green Oats	74·81	60·77	50·00	76·30	71·74	78·75
10th to 21st October 1928	Oat Silage (Pit I)	64·31	35·93	34·45	76·46	50·24	62·50
1st to 12th November 1928	Oat Silage (Pit II)	63·42	25·86	60·73	77·34	54·71	60·46
4th to 15th June 1925	Oat Hay	63·39	35·77	50·00	70·04	56·22	64·81
28th October 1925 to 16th November 1925	Do.	57·21	28·18	51·67	62·45	43·93	60·86
19th to 25th April 1927	Do.	64·63	24·21	72·84	67·73	49·32	69·59
24th April 1928 to 8th May 1928	Do.	60·62	25·15	71·44	64·29	44·18	64·67
17th to 29th September 1928	Green Maize	69·90	36·54	65·06	69·75	61·45	76·49
21st November 1928 to 8th December 1928.	Maize Silage	63·05	22·72	53·41	69·16	43·05	72·09
24th August 1928 to 6th September 1928	Green Guara	57·19	49·85	38·92	26·06	77·41	70·01

TABLE VI.

Feeding value of various fodders.

—	Per 100 lbs. of food		Albuminoid ratio	Per 100 lbs. of dry matter in feed	
	Starch equivalents	Protein		Starch equivalent	Protein
		lb.	1 :		lb.
1. Green oats	8·73	1·17	8·7	53·79	7·21
2. Oat silage	12·99	1·14	14·8	46·11	4·11
3. Oat hay	37·89	2·71	21·3	39·90	2·85
4. Green maize	12·02	0·96	13·0	58·69	4·69
5. Maize silage	13·49	0·87	17·1	52·86	3·41
6. Green guara	8·11	2·37	3·1	42·28	12·36

TABLE VII.

Analyses showing changes in content of dry matter, volatile and non-volatile organic acids, amino acids, and volatile bases undergone by the oats in the two silos per 1000 grams dry oats.

—	Green Oats C. Cs. N.	Bag I Silage C. Cs. N.	Bag II Silage C. Cs. N.	Bag III Silage C. Cs. N.	Bag IV Silage C. Cs. N.	
			SILO I.			
Volatile organic acids	166·2	797·6	584·0	584·4	430·4	
Non-volatile organic acids	842·4	....	129·5	361·1	594·7	
Amino acids	14·4	30·2	23·7	63·5	47·9	
Volatile bases	27·7	131·9	189·4	311·0	519·8	
Dry matter	1000 grams.	737·7	783·1	717·9	729·9	
			SILO II.			
					Brown.	Green.
Volatile organic acids	158·0	794·4	735·6	668·2	710·6	715·6
Non-volatile organic acids	710·5	4·5	138·9	117·3	194·5	..
Amino acids	12·5	57·1	123·7	77·5	101·9	10[illegible]·9
Volatile bases	40·6	216·2	194·2	238·6	179·3	226·8
Dry matter	1000 grams.	770·9	797·2	....	..	..
			MAIZE SILAGE.			
Volatile organic acids	....	471·4	....	....	....	
Non-volatile organic acids	....	840·4	....	....	....	
Amino acids	....	157·2	....	....	....	
Volatile bases	....	111·3	....	....	....	

Table VIII.

Showing details of daily nitrogen balance in grams.

Period	Animal	Feed	Intake	Outgo		Brushings	Total intake	Total outgo	Balance
				Dung	Urine				
25th January 1926 to 13th February 1926.	Bimla	Green Oats	52·58	14·55	12·06	Traces	52·58	26·61	25·97
Ditto	Ursula	Do.	52·58	15·18	17·11		52·58	32·29	20·29
10th to 21st October 1928	115	Oat Silage	39·29	21·06	15·70		39·29	36·76	2·53
Ditto	116	Do.	54·25	24·83	20·70		54·25	45·53	8·72
Ditto (Pit I)	117	Do.	52·34	25·91	18·87		52·34	44·78	7·56
Ditto	120	Do.	47·65	23·74	16·85		47·65	40·59	7·06
1st to 12th November 1928	115	Do.	38·88	18·85	16·30		38·88	35·15	3·73
Ditto	116	Do.	56·83	22·99	19·94		56·83	42·93	13·90
Ditto (Pit II)	117	Do.	46·29	22·21	14·73		46·29	36·94	9·35
Ditto	120	Do.	44·97	21·63	11·42		44·97	33·05	11·92
28th October 1925 to 10th November 1925.	Lucy	Oat Hay	71·21	42·18	22·66		71·21	64·84	6·37
Ditto	Alice	Do.	49·44	26·31	13·61		49·44	39·92	9·52
19th to 25th April 1927	104	Do.	36·65	22·78	11·68		36·65	34·46	2·19
Ditto	105	Do.	30·13	13·27	8·95		30·13	22·22	7·91

TABLE VIII—*contd.*

Showing details of daily nitrogen balance in grams—contd.

Period	Animal	Feed	Intake	Outgo		Brushings	Total intake	Total outgo	Balance
				Dung	Urine				
24th April 1928 to 8th May 1928	115	Oat Hay	31·22	16·77	9·59	Traces	31·22	26·36	4·86
Ditto	116	Do.	39·56	21·10	12·48		39·56	33·58	5·98
Ditto	117	Do.	33·38	18·67	10·75		33·38	29·42	3·96
Ditto	120	Do.	27·57	16·33	8·38		27·57	24·71	2·86
17th to 29th September 1928	115	Green Maize	62·04	25·32	22·42		62·04	47·74	14·30
Ditto	116	Do.	75·41	30·23	27·01		75·41	57·24	18·17
Ditto	117	Do.	65·44	24·94	25·83		65·44	50·77	14·67
Ditto	120	Do.	71·78	25·72	22·06		71·78	47·78	24·00
21st November 1928 to 8th December 1928.	115	Maize Silage	43·54	23·86	11·51		43·54	35·37	8·17
Ditto	116	Do.	56·89	33·44	13·63		56·89	47·07	9·82
Ditto	117	Do.	46·77	25·83	12·46		46·77	38·29	8·48
Ditto	120	Do.	47·79	27·34	10·42		47·79	37·76	10·03
24th August 1928 to 6th September 1928.	115	Green Guara	112·60	24·44	64·76		112·60	89·20	23·40
Ditto	116	Do.	165·50	38·36	94·45		165·50	132·81	32·69

MGIPC—M—III-1-64—24-2-30—500.

A NEW METHOD OF DISPERSING SOILS FOR MECHANICAL ANALYSIS.

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A vast amount of literature has sprung up during recent years dealing with the methods of mechanical analysis of soils. The older elutriation and beaker methods have almost entirely been replaced by pipette methods which are simpler and take very much less time.

A good deal of attention has been paid to the preliminary treatment of the soil, as the success of the newer methods essentially rests on the complete breaking up of the compound particles of the soil into the simplest units, *i.e.*, their ultimate structures.

The results of the co-operative work carried out under the auspices of the International Society of Soil Science and those of individual workers go far to show that to get at the prime particle structure of the soil it is necessary to treat it first with dilute HCl and also with H_2O_2 in some cases. This is now the basis of the International method A, recommended for universal adoption.

Without being unduly critical towards this method, it cannot be denied that the fundamental objection against acid treatment, that a considerable loss of soil constituents takes place, cannot be answered except by saying that it is inevitable, and when this loss assumes such alarming proportions as 30 to 40 per cent., as it actually does in calcareous soils with which we are familiar at Pusa, it cannot be altogether ignored. It is for this reason that a number of workers still prefer to employ a much less drastic method for dispersion so that the soil aggregates are not completely broken up. However, such methods can be of individual interest only, to enable a person to infer empirically and roughly the soil structure.

Keen has very rightly emphasized the necessity of the universal adoption of the International method[1], because in the present state of soil science, it is highly desirable to be able to compare directly one's own results with those obtained by workers in other countries.

The International method, though absolute and strictly reproducible, is by no means ideal. However, this is not an argument against its universal adoption but a plea for searching for a method that would comprise all the advantages of the

[1]Keen, B. A. *Supplements to the Proc. Int. Soc. Soil Sci.*, Vol. 1, No. 1 (1928).

International method without its inherent defect that it involves the destruction of varying amounts of soil constituents depending on the nature of the soil.

The object of the present paper is to outline such a method after tracing its development.

Forty-seven soils were used for this investigation (Table I); of these nine were calcareous, containing from 30 to 40 per cent. calcium carbonate. The soils will be referred to by their serial number.

TABLE I.

INTERNATIONAL SOILS.

Serial No.	
	Czechoslovakia.
1	Rendzina soil Cejc (sent by Dr. Novak).
2	Podsol soil Zdar (sent by Dr. Novak).
	England.
3	Hoos Fallow (Rothamsted) 18-27", collected on 4th July 1924.
	Hungary.
4	Soil from Budapest (sent by Dr. 'Sigmond).
	Egypt.
5	Badob soil for comparative analysis from Wad Medani, Sudan, No. 16419.
	United States of America.
6	Hillsdale sandy loam C (sent by Dr. Bouyoucos, U. S.).
7	Chippewa fine sandy loam B (sent by Dr. Bouyoucos, U. S
8	Onaway loam C (sent by Dr. Bouyoucos, U. S.).
9	Ontonagon clay B (sent by Dr. Bouyoucos, U. S.).
10	Michigan clay loam (sent by Dr. Bouyoucos, U. S.).
	INDIAN SOILS.
	Punjab.
11	Soil from Punjab B. D. N.
12	Lyallpur Agricultural College 27-F2 Plot No. 3.
13	Punjab Soil sent by Sir Ganga Ram (bad patch).
14	Sirsa sandy loam 384/1926 canal irrigated.
15	Sirsa loam 381/1926 canal irrigated.
16	Sirsa clay 385/1926 canal irrigated.
17	Karnal sandy loam 786/1926 well irrigated.
18	Karnal medium loam 787/1926 well irrigated.
19	Karnal clay 788/1926 well irrigated.
20	Firozpur sandy loam 778/1926 well irrigated.
21	Moga medium loam 770/1926 well irrigated.
22	Moga clay 780/1926 well irrigated.

TABLE I—*concld.*

INDIAN SOILS—*contd.*

Madras.

Serial No.		
23	Nandyal Agricultural Station, Field No. 3A, Plot No. 1.	
24	Koilpatti Agricultural Station, black soil (no manure).	
25	Bangalore soil A. T. 15.	
26	Godavari soil A. T. 16.	
27	Soil from Malabar, Enad Taluk.	
28	Clayey soil of Punja lands, Kuppa Puram (Alleppey).	
29	Acid soil. Thuravoor East Kan (Travancore).	
	Bombay.	
30	Light cotton soil, Indore (unmanured).	
31	Poona soil, Kalthi plot, light soil 2C.	
32	Manjri Dry Farming Station plot 2 control.	
33	Akola soil from pot culture house (A. T. 23).	
34	Dharwar soil, new sample (A. T. 24).	
	United Provinces.	
35	Kalianpur soil M. E. 4.	
36	Government Farm, Etawah (M. E. 11).	
	Assam.	
37	Shillong soil (A. T. 17).	
	Bengal.	
38	Dacca acid soil (sample 4 from pot culture house).	
	Calcareous soils from Pusa (Bihar)	
39	Gonhri (M. E. Series).	23·7 per cent. $CaCO_3$.
40	Bhograson (P2A).	35·6 per cent. $CaCO_3$.
41	South Pangarbi (P3).	36·9 per cent. $CaCO_3$.
42	South Pangarbi (P3A).	42·4 per cent. $CaCO_3$.
43	North Pangarbi (P4).	34·4 per cent. $CaCO_3$.
44	North Pangarbi (P4A).	38·7 per cent. $CaCO_3$.
45	Brickfield No. 1 (P12).	34·5 per cent. $CaCO_3$.
46	Brickfield No. 2 (P11).	..
47	Jhilli (P 10).	32·7per cent. $CaCO_3$.

Ammonia has been almost universally employed for the final dispersion of the soil for mechanical analysis. This is largely due to the belief that, at the time of drying the various fractions, the whole of the ammonia is driven away and thus no error is introduced by its use. However, it can be shown that this belief is erroneous; as a matter of fact, after the acid treatment, the soil, if treated with excess of ammonia and then oven-dried (100°—105° C.), retains an amount of ammonia which is approximately equivalent to the amount of alkali required to bring that soil to neutrality. In Table II are recorded values for ammonia absorption as

well as NaOH required to make the soil just alkaline (using 0·2 per cent. solution of Brom Thymol Blue as an external indicator).

In every case 10 grm. of soil were treated with dilute HCl exactly in the manner recommended for mechanical analysis. After washing free from excess of acid, it was transferred to a crystallising dish, treated with excess of $\frac{N}{10}$ ammonia solution and left in the oven overnight. Next morning ammonia was determined by distillation with lime.

Another weighed portion of the soil was similarly treated with acid and after washing was transferred into a stout beaker. $\frac{N}{10}$ NaOH was then gradually run in with frequent stirring; with a glass rod a drop of the suspension was occasionally thrown over a drop of the indicator on a porcelain tile; the production of bluish green colour was taken as the end point.

TABLE II.

Showing the equivalence between ammonia absorption and NaOH needed for bringing the soil to the neutral point.

Soil No.	NH_3 retained on oven-drying (m.eq. per 10 grm. of air dry soil)	NaOH required for neutralization (m. eq. per 10 grm. of air dry soil)
1	1·06	1·6
2	1·2	1·2
3	1·67	1·6
14	4·41	4·4
24	4·4	4·22
25	0·4	0·65
26	1·6	1·7
30	3·74	2·5
31	3·43	2·8
32	4·43	2·8
33	4·62	5·1
34	3·92	3·6
36	3·35	3·6
37	1·67	1·5
39	0·89	0·8

It is clear from Table II that if the amount of alkali does not exceed that required for bringing the soil to neutrality, the results of mechanical analysis will be always comparable whatever alkali may be used for the final dispersion. This affords a means of comparing the efficiency of various alkalies. The general conclusion may be stated as follows :—LiOH and NaOH are very much more powerful dispersing agents than NH_4OH and KOH ; ammonia is the weakest.

A comparison of the dispersing action of LiOH and NH_4OH on six soils (Table III) will make this point clear. The soils used for this purpose were acid treated as preliminary to mechanical analysis and then dried.

In the process of drying, the particles got cemented together and a comparison of the clay content by the two hydroxides will give an idea of the difference in their dispersing power. In the case of NH_4OH the suspension was shaken with 1 per cent. ammonia for 24 hours, whereas in the case of LiOH, it was simply left for 24 hours with the requisite amount of hydroxide to make it slightly alkaline. The moisture absorption at 50 per cent. humidity by various soils is also recorded in Table III.

TABLE III.

Comparison of the dispersing power of NH_4OH and LiOH.

Soil Serial No.	Clay (0·002 mm.) %		Moisture at 50 per cent. humidity
	NH_4OH	LiOH	%
24	38·44	49·8	10·05
25	23·0	18·4	0·68
26	35·4	37·16	14·04
33	38·58	*60·62	11·31
34	36·26	60·54	10·67
37	39·8	*36·2	3·42

* In these cases NaOH was used instead of LiOH.

A glance at Table III will show that ammonia is unable to disperse most of the soils after acid treatment if once they have been allowed to dry, and the results for clay content obtained by shaking such soils with ammonia show no relationship to moisture absorption, while LiOH and NaOH give maximum dispersion without any shaking at all and, on the whole, show a much better agreement between the clay content and moisture absorption.

In order to see the minimum time required for maximum dispersion of a soil by NaOH, soil No. 33 (acid treated and dried) was shaken with the requisite amount of NaOH for varying intervals of time and the clay determined immediately, after 6 hours and 24 hours. The results are recorded in Table IV.

TABLE IV.

The effect of time of shaking with NaOH on the clay content of soil No. 33.

Time of shaking (minutes)	Clay (0·002 mm) per cent.		
	Determined immediately	After 6 hours	After 24 hours
0	45·4	59·98	60·61
10	55·6	59·36	60·82
20	57·6	59·66	60·04
30	57·0	60·08	60·42
40	58·46	60·22	60·58
50	58·06	60·02	60·98

It seems that 40 minutes shaking or 6 hours standing would disperse all the clay.

A number of soils were examined both by the methods of Hissink, new English, and $\frac{N}{20}$ HCl,[1] as well as NaOH and LiOH addition after the acid treatment. As the first three methods gave closely agreeing values, their mean is only recorded. The suspension in the case of NaOH and LiOH was only occasionally shaken with hand during 24 hours. The results recorded in Table IV leave no doubt as to the superiority of NaOH or LiOH over ammonia. The difference though not very great is, on the whole, in favour of the former; and when it is remembered that shaking was entirely eliminated, this becomes all the more striking. As a rule, the suspensions were shaken for one hour when the sampling had to be done immediately.

[1] Puri, Amar Nath, and Amin, B. M. A comparative study of the Methods of Preparation of the Soil for the Mechanical Analysis, with a note on the Pippette method. *Agri. Res. Inst. Pusa Bull.* 175 (1928).

TABLE V.

Clay content of soils determined by various methods.

Soil Serial No.	Hissink, new English, $\frac{N}{20}$ HCl (mean)	* CLAY (0·002 mm.) PER CENT.		
		NaOH	LiOH	†NaCl
1	27·2	25·6	26·3	26·8
2	26·4	24·9	27·9	22·0
3	35·4	37·3	37·6	37·6
4	32·1	31·2	33·7	32·5
11	53·2	59·7	58·0	59·7
12	11·6	13·4	..	..
23	50·3	56·6	54·2	59·1
24	49·7	58·2	56·4	59·4
30	54·7	61·3	58·1	57·8
31	30·9	32·8	32·0	30·9
32	53·6	58·0	55·2	63·9
35	14·5	13·8	..	..
36	13·7	15·7	..	..
39	34·3	32·3	31·2	29·2

* All values refer to the oven dry weight of the soil.
† The significance of these values will be brought out later.

Having established that Na and Li salts of the exchange complex can be dispersed very easily, it followed that if all the other replaceable ions in a soil be replaced by Na by the action of NaCl, then this soil should disperse just as readily as if it were treated with acid followed by NaOH treatment.

A number of soils were treated with N. NaCl (5 to 6 hundred c.c. in 100 c.c. lots) and finally washed only with a small quantity of water just to displace the excess of NaCl. The suspension was shaken for one hour and analysed mechanically. These results when compared to those obtained with NaOH after the acid treatment show a very good agreement as regards the clay content (Table VI).

The results with calcareous soils are of special interest. It is clear that clay is very little affected by acid treatment, the loss in the main being confined to coarser

fractions. This is shown in a striking manner in Fig. 1 where the summation curves of two soils are given both with and without acid treatment.

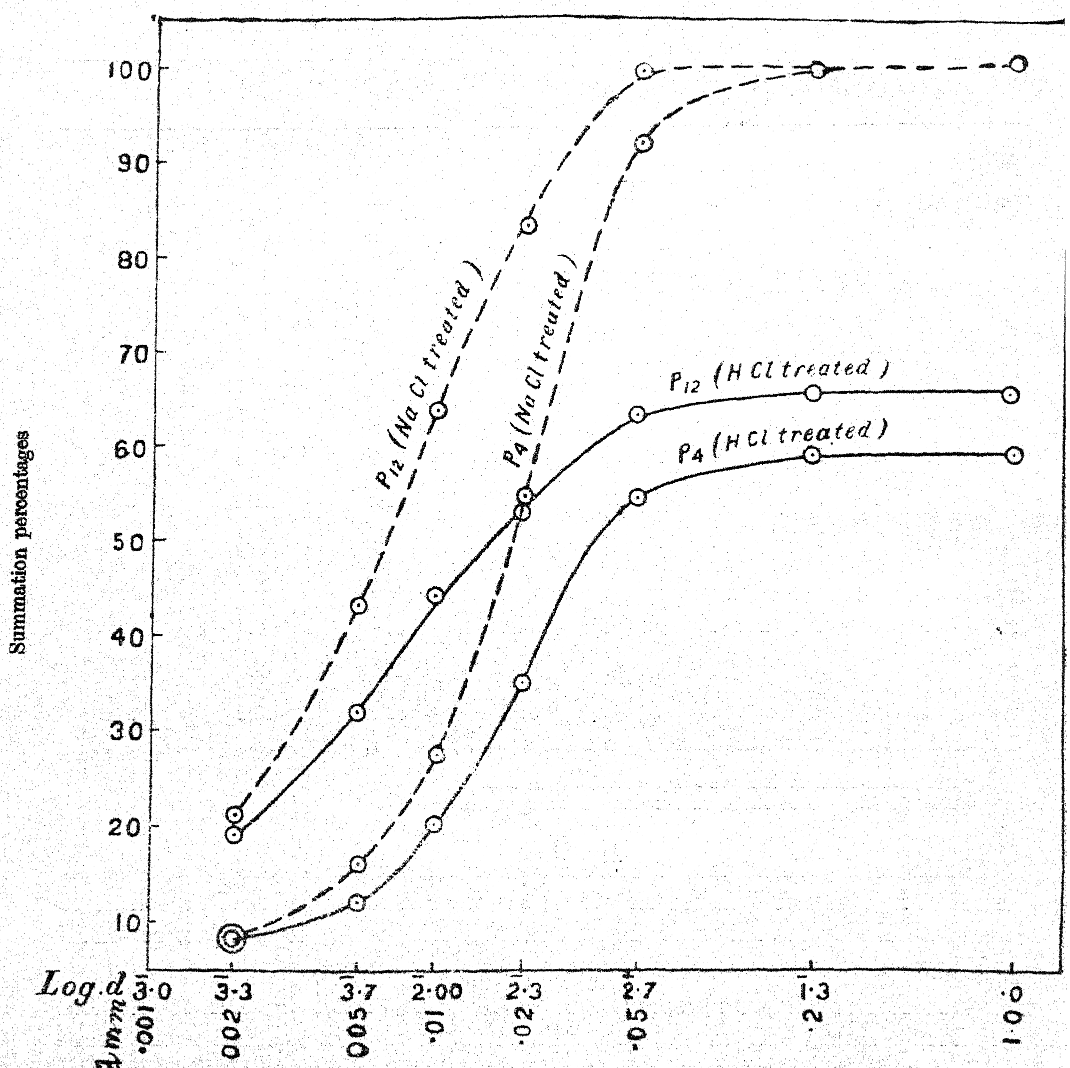

FIG. 1. Summation curves of two calcareous soils with and without acid treatment.

TABLE VI.

Mechanical analysis of soils with acid treatment (+NaOH) and without acid treatment (NaCl).

Soil Serial No.	Mechanical analysis			
	Clay (0·002 mm.) %		Silt (0·002—0·02 mm.) %	
	HCl	NaCl	HCl	NaCl
5	65·9	66·5	11·6	14·3
6	5·2	5·0	14·8	14·7
7	3·8	1·5	1·9	1·4
8	13·3	11·7	18·9	20·9
9	62·1	64·9	22·7	22·5
10	15·3	15·2	44·0	48·5
13	9·1	10·6	..	..
14	9·7	9·2	10·5	10·7
15	9·6	9·1	9·7	9·9
16	36·6	37·1	22·7	22·9
17	6·6	6·4	18·8	19·2
18	8·5	9·1	13·9	14·0
19	30·6	29·6	41·8	42·7
20	7·5	6·6	10·2	11·7
21	14·6	11·1	11·7	14·2
22	25·4	22·6	39·9	46·3
28	12·3	25·4	12·2	17·4
29	44·6	59·8	26·2	27·6
40	7·5	6·8	24·9	39·9
41	9·4	9·7	..	..
42	6·4	7·0	26·5	44·7
43	5·5	4·8	17·8	30·7
46	17·8	18·3	..	..
47	10·4	9·3	26·6	44·7

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In the NaCl treatment of the soil for mechanical analysis it is not necessary to wash the soil with water finally to get rid of the excess of the salt; in fact, the soil gets peptised so easily that it is better to wash it in the end with $\frac{N}{10}$ NaCl, which can be finally displaced by gently adding 10-20 c.c. of water or it can be got rid of by suction if washing is done in a buchner funnel. It must be remembered that Na soil is not easily flocculated by even large amounts of NaCl as will be seen from Table VII, which shows the effect of increasing amounts of NaCl on the clay content of soil No. 33. The soil was first treated with acid and neutralized with NaOH and then shaken with different amounts of NaCl for one hour. It appears that even 40 c.c. of $\frac{N}{10}$ NaCl has no appreciable effect. The actual weight of 5-10 c.c. of $\frac{N}{10}$ NaCl which might be held back by the soil, when diluted to 1000 c.c., is negligible in 25 or 50 c.c. of the suspension that is pipetted for evaporation and this cannot introduce any error.

It is also desirable to add some NaOH to the suspension after NaCl treatment just sufficient to make it alkaline to phenolphthalein, as complete dispersion can only take place in alkaline media. The presence of NaOH ensures against any danger of incomplete dispersion due to incomplete displacement of all other ions by Na or insufficient washing as the stability of the suspension is much more tolerant to the presence of neutral salts in the presence of NaOH. For instance, soil No. 33 after HCl treatment and NaOH neutralization required 160 c.c. of $\frac{N}{10}$ NaCl to produce visible flocculation, but when 40 c.c. of $\frac{N}{10}$ NaOH were added, even 270 c.c. of $\frac{N}{10}$ NaCl did not produce flocculation. The actual weight of NaOH added is usually too small to be allowed for in the weights of the various fractions.

TABLE VII.

Effect of increasing amounts of NaCl on the clay content of soil No. 33, acid treated and neutralized with NaOH.

c.c. of $\frac{N}{10}$ NaCl added to 10 grm. of soil.	Clay (0·002 mm.)
	%
0	59·4
20	58·9
25	58·8
30	59·1
35	58·0
40	58·0

The writer has never found any use for the H_2O_2 treatment chiefly advocated by English workers and Hissink[1]. In the tropics one is seldom called upon to deal with soils containing a high percentage of humus which H_2O_2 is supposed to destroy. However, if some workers wish to retain its use, there is no reason why NaCl treatment should not precede or follow the H_2O_2 treatment.

DETAILED DESCRIPTION OF THE PROPOSED METHOD.

Ten to twenty grm. of soil are left with 1 to 2 hundred c.c. of N. NaCl solution for about half an hour with occasional stirring. The suspension is then filtered and washed with about 500 c.c. of the same solution on the filter paper. It is finally washed with about 100 c.c. of $\frac{N}{10}$ NaCl solution and when the whole of it has been drained off, about 10 c.c. of water is gently poured on the soil which has been brought to the bottom of the filter paper. This displaces the major portion of NaCl. The suspension is then transferred to a stout beaker with 3 to 5 hundred c.c. of water. $\frac{N}{10}$ NaOH is then gradually run in till the suspension is just alkaline to phenolphthalein (used as an external indicator) and mechanically shaken for 1 hour or left for 5-6 hours with occasional hand-shaking, when it is ready for making up to the desired volume for the pipette method.

For washing the soils the writer found Buchner funnels of 3″ to 4″ diameter very satisfactory. For this purpose it is convenient to stick the filter paper with a little molten wax run round the edges after first moistening the paper with water and applying suction. In this way the whole of the suspension (1 to 2 hundred c.c.) can be poured in without any risk of the filter paper lifting up. Practically no soil particles enter the pores of the filter paper if the latter is of fine texture like Watman 50 ; and when washing is complete, the whole of the soil can be transferred into the shaking bottle with a jet of water.

It is not necessary to use pure NaCl for replacement. Most of the analyses recorded above were done with a sample prepared from ordinary rock salt after precipitating the bulk of Ca and Mg salts by Na_2CO_3 ; the excess of the latter was just neutralized with HCl after filtration. The resulting salt contained about 0·1 per cent. Ca and Mg salts ; these did not affect the results of mechanical analysis.

It is a great feature of this method that there are no complicated details to be followed. What is required is to replace all or at least a greater part of the ions by sodium in the exchange complex. Even shaking for one hour is not necessary ; the suspension can be put aside for few hours with occasional shaking. There is practically no loss of soil constituents, and a more rational picture of the size-distribution of the various particles is obtained than by the acid treatment.

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[1] Puri, Amar Nath, and Amin, B. M. *Loc. cit.*

SUMMARY.

1. NaOH and LiOH are much more powerful dispersing agents than ammonia which is almost universally employed for final dispersion in the mechanical analysis of soils.
2. A method of preliminary treatment of the soil for mechanical analysis is outlined, which consists in replacing all the ions by Na in the exchange complex.
3. The proposed method combines all the advantages of acid treatment as regards reproducibility and attainment of maximum dispersion, and is free from such objections as the loss of varying amounts of soil constituents that is inevitable when the soil is treated with acid.

MGIPC—M—III-1-69—29-11-29—500.

A STUDY OF THE CAPILLARY RISE OF WATER UNDER FIELD CONDITIONS.

BY

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(Received for publication on 5th August 1929.)

The earlier workers on this problem were of the opinion that subsoil water is available for crops. Thus King[1], Hall[2], Cameron[3], McGee[4], Leake[5] and others assert that there is a large upward flow of water from the subsoil due to capillarity, their individual estimates of the depth effective varying from 200 feet to a minimum of 10 feet.

On the other hand, Leather[6], Alway[7], Tulaikow[8], Mitscherlich[9], Burr[10], Rotmistrov[11] and others have stated that the flow is of no practical importance to the crop, and modern theory is of the opinion that this rise is so slow that underground water could not be raised to the surface foot of soil during the course of one growing season. The plant root must go towards the stored water and not the latter to the plant root. Keen[12], from a theoretical consideration of the ideal soil, has calculated mathematically that in the case of a heavy clay the rise of water due to capillarity may be as high as 150 feet but this he asserts to be of no avail because of the extreme slowness of the rise and of the fact that soil in the actual field does not exist in a strictly ideal state. In fact, during the great drought in 1921 when the atmospheric conditions of England resembled to some extent those of the tropics he[13] observed experimentally that the process of drying of the soil did not extend below 3 feet during the course of one growing season.

It is interesting, however, to note the difference of opinion expressed by Leather[6] and Alway and Mcdole[14] as to the actual process of capillary rise. The former, upholding the view expressed by Briggs[15] concerning the movement of soil moisture from one part to another, states that it starts essentially from the surface as evaporation takes place during the dry season following the monsoon and that it

[1] King, F. H. *Expt. Stat. Rec.* Vol. XII, p. 34.
[2] Hall, A. D. The Soil, 1904, p. 94.
[3] Cameron, F. K. The Soil Solution, 1911.
[4] McGee, W. J. *U. S. Dept. Agric. Bur. Soils Bul.* 92 and 93.
[5] Leake, H. M. *Jour. Agric. Science*, Vol. 1, 1905-06, p. 454.
[6] Leather, J. W. *Mem. Dept. Agric. India, Chem. Ser.*, Vol. 1, 1908, No. 6.
[7] Alway, F. J. *U. S. Dept. Agric. Bur. Plant Indus. Bul.* 130, p. 17.
[8] Tulaikow, N. *Abstract in Russ. Jour. Exp. Landw.*, t. 8, kinga 6, p. 664.
[9] Mitscherlich, E. A. Bodenkunde für Land-und Fortwrite, 1913, p. 136.
[10] Burr, W. W. *Nebr. Agr. Expt. Stat., Research Bul.* 5, 1914, p. 88.
[11] Rotmistrov. The Nature of Drought according to the evidence of the Odessa Experimental Field. 1913, p. 48.
[12] Keen, B. A. *Jour. Agric. Sci.*, Vol. 9, 1918-19, p. 396.
[13] Keen, B. A. *Proceedings and Papers of the first International Congress of Soil Science*, June 1927. Vol. 1, p. 504.
[14] Alway, F. J., and Mcdole, G. R. *Jour. Agric. Res.*, Vol. 9, 1917, p. 27.
[15] Briggs, L. *U. S. Dept. of Agric. Div. Soil Bull* 10.

extends to a very limited depth. The depth, however, will increase with the length of the season.

On the contrary, Alway and Mcdole expressed as follows :—the deeper subsoil moisture will be able to move upwards very slowly and through such a short distance in a single season that it will be of no practical value to the plant. Further experiments extending over a long time are necessary to decide definitely whether the deep subsoil may not in a decade or so contribute sufficient moisture to the subsoil within the roots of the perennials.

From the last portion of the remark, it is obvious that Alway and Mcdole are thinking of the process of the lifting of water by capillarity as going on deep in the subsoil continually without starting essentially from the surface. Owing to great variation in climatic conditions, in the nature of the soil as also in conditions of the subsoil such as water table, etc., both the opinions expressed above by these investigators from the two entirely different parts of the world may be correct, but so far as the present work is concerned, the author finds that his results from fields which are practically flooded with heavy rainfall in the course of three months (during which period the underground water level rises from below 20 feet to within 11 feet of the surface, Table II), agree with the opinion expressed by Leather that there is no indication of upward movement of water below the 'limited' depth. Incidentally it may be mentioned that one of the fields chosen for this particular work is the same field from which Leather drew his conclusions twenty years ago. Further, Leather made direct observations on moisture, a procedure quite different from that employed in the experiments recorded in the present paper.

In connection with the work on the movement of nitrate in the soil (conducted elaborately under the Imperial Agricultural Chemist at Pusa), the author noticed that the amount of soluble salts present in Pusa soils to a depth of about 9 feet can be very conveniently obtained with a certain degree of accuracy from a measure of the electrical conductivity of the aqueous extracts and this incidentally fortunate fact was utilized in conducting the present investigation as a part of the main soil nitrate work.

At any particular depth the amount of total soluble salts in a given volume of soil at a particular time is definite, but the amount continuously changes from time to time owing to two main factors : one biological, the other the movement of water either upwards or downwards. In Pusa soil containing 30 to 35 per cent. of lime, nitrification is found to be one of the chief biological factors. On the other hand, it is known that, if water is added to a dry or semi-dry soil, biological activities go on very rapidly in the beginning but slow down to equilibrium in the course of a few weeks. Now the atmospheric conditions of Northern India are such that there is practically a continuous drought for about eight months from the middle of October to the middle of June, during which period (Table I) the total rainfall scarcely exceeds 3 inches, while in the course of the following three months, from the middle of June to the middle of September, there is as much as

40 to 45 inches of rainfall. Consequently it was thought that sufficient time, say a couple of months, should be allowed to elapse after the end of the rainy season, so that biological activities in soil might attain equilibrium. It might then be possible to trace the moisture movement by measuring the total soluble salts at various depths as explained below together with the amount of nitrification from time to time as the drying season proceeded.

Experimental procedure.

In order to understand the principle of the method, it is necessary to refer to diagram A.

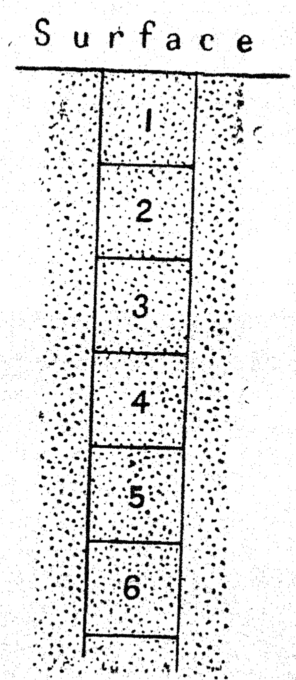


Diagram A.

Consider a cylinder of soil as it exists in the field, of given cross-section and divided into equal depths of 6 inches. Let us assume that sufficient time has been allowed after the rainy season for the biological activities to attain equilibrium. If the apparent densities of the soil for each depth are known, the total weight of soil in each unit cylinder can be calculated. Similarly the total amount of soluble salts in any unit cylinder at any given time can be obtained by determining the salt present in a known weight of soil sampled from that unit cylinder. Addition of the separate salt figures for each unit gives the total amount contained in the

whole cylinder. Let us suppose that in an actual experiment on 1st of January the total salt content for the first five units (*i.e.*, down to 2′ 6″) is 1·234 grams and that the amount present in the fifth alone (*i.e.*, 2′ 0″ to 2′ 6″) is 0·213 grams. A month later, *i.e.*, on 1st of February, suppose it is found that the amount for depth 5 (*i.e.*, fifth unit) has fallen from 0·213 to 0·198. This decrease may be due to either of the two causes, *viz.*,—

(1) that moisture has percolated downwards to depth 6 carrying along with it soluble salts and that either no moisture has come down from depth 4 or that which has come down is insufficient to make good the loss.

(2) that some moisture has moved up from this depth 5 to depth 4 and that either no moisture has come up from below or that which has come up is insufficient to compensate for that lost.

It will not be difficult to see that the total amount 1·234 grams for the whole of the 5 depths will for case (1) be diminished and for case (2) either increase or remain the same according as any moisture from depth 6 has moved up into depth 5 or not.

Similarly suppose on the 1st of February instead of a decrease there is actually an increase in the amount of soluble salts for depth 5 from 0·213 to 0·228 grams. This also may be due to two causes, *viz.*,—

(1) that some moisture has percolated down from depth 4 to depth 5 and that either no moisture has moved downwards from depth 5 or that which has gone down is not so much as has come from depth 4.

(2) that more moisture has come up from depth 6 to depth 5 than has moved up from depth 5 to depth 4.

The total amount 1·234 grams for the 5 depths for case (1) will decrease or remain the same according as to whether moisture has moved down from depth 5 or not, while for (2) the value 1·234 grams would simply increase.

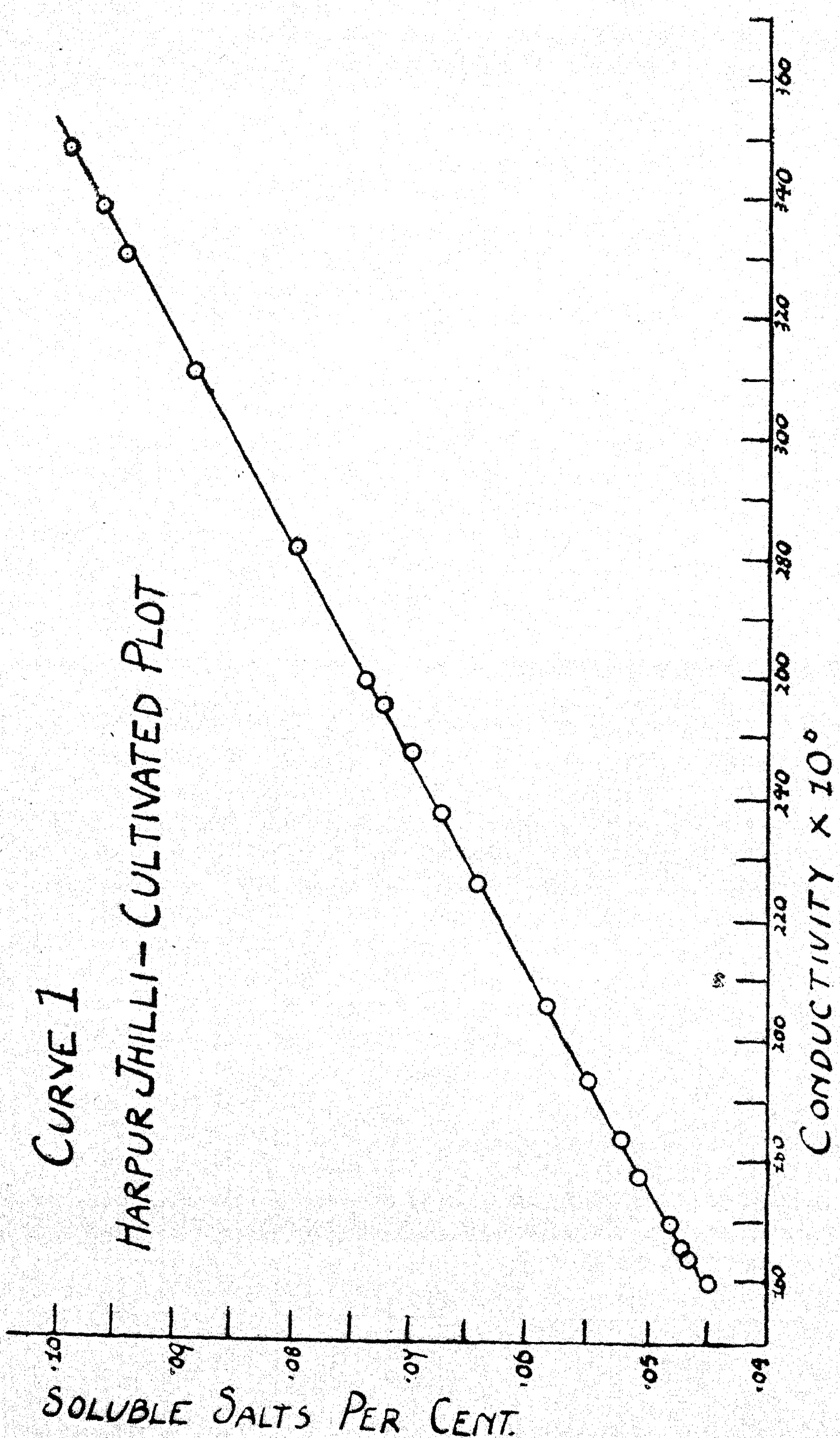
Thus we see that an increase or decrease in the amount of total solid of any single depth does not tell us whether moisture has moved up or moved down from it; but an increase or decrease in the total amount of soluble salts obtained by adding up the separate amounts for all the depths beginning from the surface down to the depth in question, at once indicates whether moisture has moved up to that depth from below or is still draining downwards from it. Hence, by keeping a record of the total amount of soluble salts for each individual depth, starting from the surface from time to time as the drying season proceeds and periodically adding up all these values from the top down to any particular depth and comparing the two values thus obtained on two different occasions, we can easily see whether moisture has moved downwards or upwards during that period from the particular depth in question.

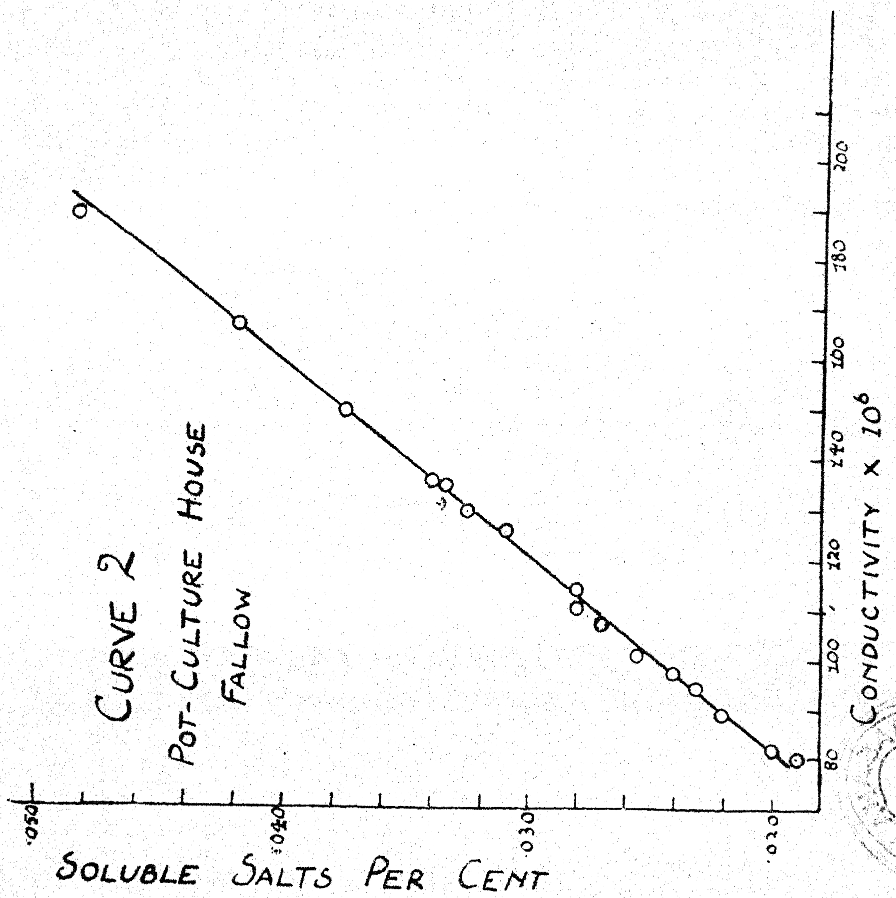
In the actual field, however, as has already been stated, a change in the salt content for any particular depth will not be entirely due to moisture movement alone but to some extent to biological factors such as nitrification, etc. Conse-

quently a determination of the amount of nitrate for each depth is made along with the measurement of the total salt content from time to time. This nitrate figure, (calculated in the form of $Ca(NO_3)_2$ since Pusa soil contains an exceptionally high percentage of lime), is deducted from the total solid figure in each case to give the amount of soluble salts whose variation may be caused by moisture movement.

Soil borings in connection with the soil nitrate work were being regularly taken from square plots marked out by pegs in several fields and for the present work such borings from a fallow and a cropped field respectively were chosen. These borings were taken at intervals of three to four weeks and were carried down to 9 feet divided into 18 depths of 6 inches. The borings on a particular day were taken about 2 feet away from that taken on a day 3 or 4 weeks previously. The borer was a uniform iron cylinder of about 2·2 inches in diameter and 9 inches long. The principle and full details of the borings are given in the paper by Leather. The nitrate determinations were made in the fresh soil by the phenol disulphonic acid method using Lovibond's tintometer. A portion of the sample of soil from each depth was dried in air at room temperature. It was then passed through a sieve of 100 meshes to the inch; and 100 grams of this sampled soil, correct to the first place of decimals, were weighed out and mixed in a bottle with 500 c.c. of conductivity water. The mouth of the bottle was then closed by means of an ordinary cork coated with paraffin wax, and the mixture shaken vigorously for one minute so as to mix the soil and water thoroughly. The bottle was then left in a thermostat maintained at 30°C for twenty-four hours. It was necessary to leave the mixture in a thermostat since the salt content of the extract was found to be slightly affected by the temperature during the period of this 24 hours' extraction. The Government Chemist[1] in the Sudan also noticed a similar effect in the case of Sudan soils. The electrical conductivity of the extract after 24 hours' standing was measured by means of metre-bridge and standard resistances. Using Pusa soil, it was found that the conductivity of the mixture of soil and water, if thoroughly shaken before measurement, was the same as that of the clear extract obtained by filtration through a chamberlain's candle in a Houston pump or of the slightly turbid extract got by centrifuging for about ten minutes. During the course of preliminary investigations, 100 c.c. of the clear extract obtained by filtering through Houston pump were discharged from a calibrated pipette on to a platinum basin dried to constant weight. The extract was then evaporated on a water bath and dried (in an oven at 100°C) to constant weight so as to give the total amount of soluble salt. It should be noted that special care was required in carrying out the evaporation, drying and weighing since the amounts obtained by evaporation were so small that perfect accuracy in weight up to the fourth place of decimals was found necessary. By taking all possible precautions it was found that the graph of percentage of soluble salts against conductivity of the extract was a straight line—curve 1 for cropped plot and curve 2 for fallow plot. In this paper all the

[1] The Report of the Government Chemist, Sudan, 1924, p. 23.


CURVE 1
HARPUR JHILLI - CULTIVATED PLOT
CONDUCTIVITY × 10
SOLUBLE SALTS PER CENT.



salt contents of the various depths of soils were calculated by referring the conductivity of the extracts to either of these curves according to the plots.

As soil borings for the present work were carried to 9 feet below the surface by means of cylinders of 2·2 inches in diameter, we shall consider for the sake of simplicity a uniform cylinder of soil 2·2 inches in diameter and 9 feet long divided into 18 depths of 6 inches. The volume of each of these depths is evidently 375·5 cm., and consequently knowing the apparent density of soil at each depth (a record of which is kept by the Imperial Agricultural Chemist), the total weight (dry) of soil occupying the whole of that depth can be easily obtained. And since the amount of soluble salts present in 100 grams of dry soil bored on a particular day from that depth is known from the conductivity figure, the total amount of soluble salts present on that day in the whole of the soil occupying that depth is easily calculated. From the figure thus obtained (Table III for cropped plot), the amount

of nitrate as $Ca(NO_3)_2$ (Table IV for the same plot) present in the depth on that day is deducted to give the amount of soluble salt whose alteration might be caused by moisture movement. Nitrification is considered as one of the chief biological activities in Pusa soil, but the amount of nitrate (Table IV) that is produced at any time below the surface foot is so small that it will not materially affect the results and general conclusions, whether it be deducted from the total salt content or not. Consequently attention is drawn to the fact that though the assumption with regard to other biological activities remaining in equilibrium may not be altogether free from objection, the very low values of nitrification that were obtained below the surface foot as well as the regularity in the content of soluble salts of any particular subsoil depth with a distinct tendency to fall with time, lead one to doubt whether biological activities in the subsoil are really sufficiently vigorous to change materially the total salt content at any time of the year. The slight changes that do occur may be due mostly to percolation of the moisture and the consequent washing of the soluble materials.

The depth of the level of the underground water of the Pusa soil from time to time as indicated by the level of water in a well situated about 100 yards from the fallow plot under investigation is given in Table II.

Experimental Results and Discussions.

Results and Discussions.

Table I.

Rainfall from June 1, 1925, to May 31, 1926.

Month	Rainfall in inches	Month	Rainfall in inches	Month	Rainfall in inches
June 1925 . .	4·97	Oct. 1925 . .	0·17	Feb. 1926 . .	0·00
July „ . .	9·10	Nov. „ . .	0·17	Mar. „ . .	0·26
Aug. „ . .	14·78	Dec. „ . .	0·00	Apr. „ . .	0·43
Sept. „ . .	16·38	Jan. 1926 . .	0·86	May „ . .	0·60
Total .	45·23	Total .	1·20	Total .	1·29

Rainfall from 1st to 17th June, 1926—0·68 inches.

Table II.

Depth of the water level in a well situated about 100 yards from the fallow plot.

Date	Depth of water level	Date	Depth of water level
20th July 1925	21′ 4″	14th Dec. 1925	18′ 9″
10th Aug. 1925	20′ 10″	4th Jan. 1926	19′ 3″
24th Aug. 1925	18′ 9″	1st Feb. 1926	19′ 11″
31st Aug. 1925	16′ 2″	22nd Feb. 1926	20′ 2″
7th Sept. 1925	11′ 11″	22nd Mar. 1926	20′ 5″
14th Sept. 1925	10′ 11″	19th April 1926	20′ 11″
28th Sept. 1925	11′ 9″	17th May 1926	21′ 7″
5th Oct. 1925	13′ 7″	14th June 1926	21′ 11″
12th Oct. 1925	15′ 1″	12th July 1926	22′ 3″
2nd Nov. 1925	17′ 1″	26th July 1926	21′ 8″
16th Nov. 1925	17′ 9″	9th Aug. 1926	20′ 8″

Table III.

Harpur Jilli—Cultivated Plot.

The figures below represent the total soluble salt content (interpolated from salt content conductivity curve) present in each depth. The values are for 375·5 c.c. of dry soil.

Depth	Total soluble salts in grams on								
No.	19-11-25	17-12-25	8-1-26	4-2-26	25-2-26	25-3-26	29-4-26	20-5-26	17-6-26
1	·5248	·5351	·5424	·5506	·5724	·6051	·6601	·7150	·7251
2	·2988	·2806	·2649	·2549	·2398	·2267	·2070	·2115	·2696
3	·2789	·2696	·2544	·2320	·2266	·2111	·1988	·1960	·1835
4	·3893	·3840	·3784	·3759	·3510	·3527	·3307	·3077	·2820
5	·4118	·4004	·3891	·3843	·3813	·3592	·3709	·3681	·3620
6	·3987	·3928	·3861	·3815	·3787	·3736	·3535	·3489	·3461
7	·3681	·3489	·3320	·3180	·3046	·2912	·2852	·2604	·2610
8	·3549	·3423	·3320	·3447	·3208	·3141	·3071	·3040	·2860
9	·2785	·2442	·2243	·2093	·1964	·1872	·1815	·1771	·1661
10	·2404	·2313	·2122	·1964	·1846	·1714	·1612	·1556	·1543
11	·2791	·2856	·2944	·2856	·2709	·2582	·2467	·2491	·2349
12	·2856	·2829	·2738	·2679	·2644	·2603	·2679	·2663	·2591
13	·2991	·3056	·2873	·2856	·2788	·2738	·2703	·2826	·2717
14	·2536	·2445	·2428	·2500	·2368	·2428	·2401	·2357	·2302
15	·2664	·2664	·2632	·2642	·2664	·2632	·2601	·2555	·2536
16	·2835	·2802	·2852	·2816	·2791	·2802	·2791	·2748	·2720
17	·2632	·2603	·2570	·2541	·2522	·2495	·2495	·2476	·2442
18	·2606	·2570	·2541	·2495	·2492	·2463	·2477	·2476	·2443

TABLE IV.

Harpur Jhilli—Cultivated Plot.

The amount of nitrate in grams calculated as $Ca(NO_3)_2$ in soil occupying the whole of each depth of 375·5 c. cm. is given below :—

Depth No.	Amount of nitrate in grams on 19-11-25	17-12-25	8-1-26	4-2-26	25-2-26	25-3-26	24-4-26	20-5-26	17-6-26
1	·0087	·0050	·0014	·0008	·0010	·0013	·0011	·0045	·0095
2	·0039	·0027	·0009	·0010	·0008	·0012	·0008	·0021	·0051
3	·0020	·0029	·0015	·0010	·0008	·0011	·0005	·0009	·0007
4	·0022	·0032	·0015	·0010	·0009	·0010	·0005	·0008	·0010
5	·0024	·0033	·0013	·0011	·0009	·0010	·0005	·0006	·0006
6	·0020	·0026	·0012	·0010	·0011	·0010	·0006	·0009	·0004
7	·0018	·0019	·0012	·0009	·0009	·0010	·0005	·0008	·0004
8	·0018	·0015	·0012	·0011	·0008	·0008	·0006	·0008	·0002
9	·0016	·0015	·0013	·0008	·0008	·0008	·0006	·0006	·0002
10	·0017	·0016	·0013	·0011	·0008	·0008	·0005	·0006	·0002
11	·0028	·0018	·0014	·0012	·0012	·0012	·0007	·0012	·0002
12	·0016	·0019	·0015	·0012	·0010	·0012	·0007	·0010	·0005
13	·0019	·0018	·0015	·0013	·0010	·0013	·0005	·0013	·0013
14	·0021	·0018	·0014	·0012	·0010	·0012	·0005	·0010	·0001
15	·0129	·0019	·0010	·0013	·0010	·0013	·0007	·0010	·0008
16	·0063	·0020	·0016	·0010	·0010	·0013	·0008	·0001	·0008
17	·0029	·0020	·0016	·0010	·0017	·0012	·0005	·0008	·0005
18	·002	·0021	·0010	·0013	·0011	·0011	·0007	·0005	·0011

TABLE V.

Harpur Jhilli—Cultivated Plot.

This table gives the total soluble salt contents from which the nitrate figures (Table IV), estimated as $Ca(NO_3)_2$, have been subtracted. Only the values for the first 6 feet are given as others are unnecessary.

Depth No.	Amount of soluble salts in grams on 19-11-25	17-12-25	8-1-26	4-2-26	25-2-26	25-3-26	24-4-26	20-5-26	17-6-26
1	·5161	·5301	·5410	·5498	·5714	·6038	·6590	·7105	·7156
2	·2949	·2779	·2640	·2539	·2390	·2255	·2062	·2094	·2645
3	·2760	·2667	·2529	·2310	·2258	·2100	·1983	·1951	·1828
4	·3871	·3808	·3769	·3749	·3502	·3517	·3302	·3069	·2810
5	·4094	·3971	·3878	·3832	·3804	·3582	·3704	·3675	·3614
6	·3967	·3902	·3849	·3805	·3776	·3726	·3529	·3480	·3457
7	·3663	·3470	·3308	·3171	·3037	·2902	·2847	·2596	·2606
8	·3531	·3408	·3308	·3436	·3200	·3133	·3065	·3032	·2858
9	·2769	·2427	·2230	·2085	·1956	·1864	·1809	·1765	·1659
10	·2387	·2297	·2109	·1953	·1838	·1706	·1607	·1550	·1541
11	·2763	·2838	·2930	·2844	·2697	·2570	·2460	·2379	·2347
12	·2840	·2801	·2723	·2667	·2634	·2591	·2672	·2653	·2686

Table VI.

Harpur Jhilli—Cultivated Plot.

In this table the figures against each depth represent the amount of soluble salts in grams present in the cylinder of soil of 2·2 inches in diameter and of height equal to the distance of the lowest point of the particular depth in question from the surface of the field. They are obtained by adding up all the figures in Table V beginning from the corresponding depth and going vertically upwards to the first depth. That is to say, the first figure ·8110 grams against depth 2 in this table is obtained by adding up the first figures ·2949 grams and ·5161 grams against depths 2 and 1 in Table V. Similarly the first figure 1·0870 grams against depth 3 in this table is obtained by adding up the first three figures ·2760, ·2949 and ·5161 grams of the first vertical column of Table V and so on.

Depth		Summation totals of salt in grams on								
No.	in ft. & in.	19-11-25	17-12-25	8-1-26	4-2-26	25-2-26	25-3-26	24-4-26	20-5-26	17-6-26
1	0′ 0″—0′ 6″	·5161	·5301 +	·5410 +	·5498 +	·5714 +	·6038 +	·6590 +	·7105 +	·7156 +
2	0′ 6″—1′	·8110	·8080 —	·8050 —	·8037 —	·8104 +	·8293 +	·8652 +	·9199 +	·9801 +
3	1′—1′ 6″	1·0870	1·0747 —	1·0579 —	1·0347 —	1·0362 +	1·0393 +	1·0635 +	1·1150 +	1·1629 +
4	1′ 6″—2′	1·4741	1·4555 —	1·4348 —	1·4096 —	1·3864 —	1·3910 +	1·3937 +	1·4219 +	1·4439 +
5	2′—2′ 6″	1·8835	1·8526 —	1·8226 —	1·7928 —	1·7668 —	1·7492 —	1·7641 +	1·7894 +	1·8053 +
6	2′ 6″—3′	2·2802	2·2428 —	2·2075 —	2·1733 —	2·1444 —	2·1218 —	2·1170 —	2·1374 +	2·1510 +
7	3′—3′ 6″	2·6465	2·5898 —	2·5383 —	2·4904 —	2·4481 —	2·4120 —	2·4017 —	2·3970 —	2·4116 +
8	3′ 6″—4′	2·9996	2·9306 —	2·8691 —	2·8340 —	2·7681 —	2·7253 —	2·7082 —	2·7002 —	2·6974 —
9	4′—4′ 6″	3·2765	3·1733 —	3·0921 —	3·0425 —	2·9637 —	2·9117 —	2·8891 —	2·8767 —	2·8633 —
10	4′ 6″—5′	3·5152	3·4030 —	3·3030 —	3·2378 —	3·1475 —	3·0823 —	3·0498 —	3·0317 —	3·0174 —
11	5′—5′ 6″	3·7915	3·6868 —	3·5960 —	3·5222 —	3·4172 —	3·3393 —	3·2958 —	3·2696 —	3·2521 —
12	5′ 6″—6′	4·0755	3·9669 —	3·8683 —	3·7889 —	3·6806 —	3·5984 —	3·5630 —	3·5349 —	3·5107 —

The positive or negative sign below each figure in the table above indicates whether the latter is greater or less than the preceding figure in the same horizontal line. A positive sign indicates the time when moisture has started coming up from the lower depths into the particular depth in question, while a negative sign states that moisture is still draining downwards from this depth.

TABLE VII.

Pot Culture House—Fallow Plot.

This table corresponds to Table VI for the Cultivated Plot.

Depth		Summation totals of salt in grams on								
No.	in ft. & in.	18-11-25	16-12-25	7-1-26	3-2-26	24-2-26	24-3-26	23-4-26	19-5-26	16-6-26
1	0′ 0″—0′ 6″	·1469	·1507 +	·1533 +	·1579 +	·1617 +	·1727 +	·1844 +	·2003 +	·2198 +
2	0′ 6″—1′	·2959	·2949 —	·2930 —	·2948 +	·2985 +	·3074 +	·3151 +	·3263 +	·3459 +
3	1′—1′ 6″	·4464	·4359 —	·4294 —	·4287 —	·4268 —	·4363 +	·4413 +	·4487 +	·4635 +
4	1′ 6″—2′	·6027 —	·5894 —	·5813 —	·5780 —	·5747 —	·5782 +	·5826 +	·5923 +	·6059 +
5	2′—2′ 6″	·7530	·7323 —	·7220 —	·7171 —	·7110 —	·7083 —	·7135 +	·7247 +	·7363 +
6	2′ 6″—3′	·8913 —	·8656 —	·8551 —	·8506 —	·8439 —	·8419 —	·8399 —	·8498 +	·8634 +
7	3′—3′ 6″	1·0373 —	1·0045 —	·9943 —	·9878 —	·9786 —	·9752 —	·9707 —	·9771 +	·9938 +
8	3′ 6″—4′	1·1773	1·1363 —	1·1233 —	1·1142 —	1·1035 —	1·0968 —	1·0892 —	1·0921 +	1·1053 +
9	4′—4′ 6″	1·3188	1·3696 —	1·2526 —	1·2418 —	1·2278 —	1·2179 —	1·2063 —	1·2034 —	1·2099 +
10	4′ 6″—5′	1·4586	1·3997 —	1·3805 —	1·3628 —	1·3461 —	1·3323 —	1·3178 —	1·3105 —	1·3141 +
11	5′—5′ 6″	1·6200	1·5542 —	1·5332 —	1·5093 —	1·4924 —	1·4769 —	1·4574 —	1·4466 —	1·4404 —
12	5′ 6″—6′	1·7828	1·7063 —	1·6844 —	1·6583 —	1·6364 —	1·6170 —	1·5937 —	1·5762 —	1·5654 —
13	6′—6′ 6″	1·9590	1·8791 —	1·8503 —	1·8260 —	1·8023 —	1·7794 —	1·7466 —	1·7268 —	1·7137 —
14	6′ 6″—7′	2·1559	2·0727 —	2·0420 —	2·0175 —	1·9951 —	1·9717 —	1·9353 —	1·9186 —	1·8993 —

Table VIII.

Harpur Jhilli—Cultivated Plot.

Depth	Percentage of soil moisture at various depths on								
No.	19-11-25	17-12-25	8-1-26	4-2-26	25-2-26	25-3-26	24-4-26	20-5-26	17-6-26
1	20·9	19·5	20·1	19·7	12·9	9·9	7·8	7·5	17·1
2	23·7	21·9	19·4	18·6	12·2	12·6	10·0	10·5	12·9
3	19·6	18·9	17·1	13·9	13·3	10·7	9·5	9·5	10·1
4	24·1	24·0	23·3	23·5	20·4	20·4	14·1	17·5	13·8
5	25·3	25·0	23·5	24·1	23·1	20·5	20·6	21·5	20·6
6	24·8	21·5	22·3	18·8	20·9	16·9	22·0	22·3	19·6
7	23·3	23·4	22·0	21·8	21·0	16·2	12·8	14·7	15·4
8	21·4	20·5	20·1	16·5	16·5	14·3	17·8	17·9	18·2
9	25·1	18·0	17·7	15·3	13·9	9·1	16·8	12·9	13·3
10	25·6	24·7	20·3	17·0	16·8	17·0	15·6	10·6	14·7
11	26·4	27·1	27·9	27·0	26·9	25·9	24·1	22·2	22·9
12	28·6	28·3	27·6	26·9	26·6	26·6	27·4	26·4	26·4
13	24·9	25·4	23·6	23·8	23·1	22·7	22·5	23·6	22·6
14	24·2	25·5	23·9	22·4	25·4	22·0	23·9	22·4	22·2
15	24·0	25·9	28·0	27·1	27·8	26·9	26·9	27·2	24·5
16	27·5	27·2	32·0	30·7	30·5	28·4	29·3	30·2	27·4
17	28·9	29·0	26·4	24·4	39·9	29·3	27·6	27·7	29·3
18	29·4	29·6	26·2	27·7	32·4	28·9	27·4	28·0	29·0

Pot Culture House—Fallow Plot.

Depth	Percentage of soil moisture on								
No.	18-11-25	16-12-25	7-1-26	3-2-26	24-2-26	24-3-26	23-4-26	19-5-26	16-6-26
1	14·4	15·3	16·3	14·0	10·8	9·9	7·6	7·4	5·4
2	15·8	14·5	14·4	13·2	17·1	14·6	12·2	9·6	9·6
3	17·6	15·5	17·6	17·3	18·1	16·3	13·6	13·1	12·7
4	16·8	16·9	17·3	13·4	18·6	14·6	13·8	13·3	11·8
5	18·5	14·9	14·0	15·1	12·6	15·4	13·1	9·8	7·4
6	16·2	14·9	15·8	12·4	12·5	11·6	9·1	8·5	6·9
7	17·1	15·1	13·4	12·0	11·9	11·5	10·2	7·8	6·8
8	18·6	15·6	14·5	13·2	11·8	11·0	9·5	8·7	6·8
9	19·9	16·5	13·7	14·3	13·4	11·0	10·7	9·2	7·8
10	23·0	18·5	17·8	15·3	14·6	12·8	11·8	8·7	10·5
11	25·8	23·0	22·5	20·5	20·1	19·0	15·7	15·7	13·5
12	26·3	22·3	21·7	20·6	18·9	17·3	15·5	13·6	12·1
13	26·7	25·8	23·9	24·6	23·7	22·2	19·1	18·3	17·8
14	26·0	25·3	24·8	24·9	24·9	24·8	23·8	24·7	22·9
15	26·9	26·9	26·3	26·2	26·5	26·5	25·8	25·7	25·5
16	28·3	28·3	27·0	27·8	28·3	28·5	26·7	27·0	27·2
17	27·9	27·3	27·7	27·9	28·4	24·9	27·4	27·5	26·8
18	28·3	28·6	28·0	28·7	27·5	28·3	27·5	26·1	26·9

From an examination of Table VI, it will appear that almost all the positive signs lie on one side and the negative signs on the other and that it is possible to separate them by means of a curve resembling a stair-case. A curve thus drawn as shown in the table clearly indicates the time when moisture from a particular depth is moving up into the depth immediately above it. Thus we find that moisture from depth 4 is moving up into depth 3 towards the latter part of February, while the same is happening from depth 5 to depth 4 towards the end of March and so on until we come to the middle of June when the moisture from depth 8 is just moving up to depth 7. Now the fact that moisture is moving up from depth 8 does not necessarily mean that moisture has reached the top. In fact, the process is so slow as appears from the curve that that moisture will scarcely move up to depth 5 by the end of July. By that time the heavy rainfall due to the monsoon will arrive. The whole system of moisture movement will be altered and in place of upward flow there will be a continuous downward movement for the next three months. So that it is evident that at the best, moisture from depth 5, *i.e.*, from about 2 feet 6 inches below, might move up to the surface foot at the end of the drying season and all moisture below that depth for this particular field cannot be of utility to crops unless their roots go down to those regions. Another interesting fact is revealed by the curve, *viz.*, that the upward movement of moisture in these fields starts from the surface and as the drying season proceeds, the process slowly but steadily extends downwards. This is, of course, in conformity with Leather's observations.

It should be mentioned that this particular Harpur Jhilli field was under oats which ripened towards the end of February and were harvested late in March. Now the crop itself must have depleted the top soil of some of its soluble materials and at the same time must have checked considerably direct evaporation of moisture from the surface. Both these facts will tend to reduce the calculation of the distance of the lowest depth from which moisture is just beginning to move up towards the latter part of June. Consequently the actual final depth for this particular field instead of being 3 feet 6 inches might have been say 4 feet 6 inches if there were no crop in the field. This is evident from Table VII for the fallow plot where moisture is just moving up from below five feet towards the end of the dry season. But the fact remains the same, *viz.*, moisture below 2′ 6″ or 3′ can seldom move up to the surface foot and thus be available for shallow rooted crops. Incidentally it may be mentioned that Leather from his moisture determinations from this particular fallow plot calculated the maximum depth from which water starts moving up towards the end of June and found it to be 6 to 7 feet. His result is slightly higher than that obtained in the present investigation.

Conclusions.

1. Evidence is obtained in this paper, in conformity with the present day idea of the capillary rise of water in soil, that the rise is limited to within a few feet from the surface.

2. Moisture below 3 feet can seldom move up to the surface and be available for plants unless the roots of the plants themselves go down to these depths.

3. In Indo-Gangetic alluvium where there is a heavy rainfall of 40 to 45 inches in the course of three months and where the underground water-table moves up to within 10 to 12 feet from the ground level, the process of upward movement of moisture starts from the surface extending downwards although very slowly as the drying season proceeds.

4. Moisture below 5 to 6 feet in these alluvia probably goes on percolating all the year round.

The above work was investigated in conjunction with the soil nitrate—work conducted elaborately under the Imperial Agricultural Chemist during the tenure of my Post-graduate Studentship at the Agricultural Research Institute at Pusa, and I take this opportunity of acknowledging my indebtedness to him and his staff for kindly supplementing me with the nitrate and other necessary data. I am also much indebted to Dr. B. A. Keen, of Rothamsted, who very kindly went through the manuscript and suggested some suitable alterations. My thanks are also due to the Department of Agriculture, Bengal, for kindly granting me a research scholarship to meet the college expenses during the tenure of my studentship at Pusa.

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SILAGE INVESTIGATIONS AT BANGALORE

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OBJECT.

The process of ensilage, though well known to European and American farmers for a very long time, is comparatively new to the Indian agriculturists. It has, however, been practised on an extensive scale by all the agricultural departments in this country for some years. Considerable work has also been done on silage at Nagpur,[1] Lyallpur[2], Pusa[3], etc. The Nutrition Section of the Imperial Department of Agriculture, being most concerned with the feeding values of the various fodders, has conducted several experiments in which the remarkable efficiency of silage has been demonstrated[4]. Though this fact has been established again and again by various experimenters, the reason for this efficiency has not been clearly defined. The Nutrition Section has found that high digestibility is a characteristic of silage rations. Hence this question of the reason for the high digestibility of silage was taken up for investigation.

As a preliminary to that study, it was considered essential to conduct an experiment on the usual standard lines on ensilage. The following is an account of the study of the changes taking place in the various constituents of *jowar* (*Sorghum vulgare*) during ensilage.

METHOD OF EXPERIMENT.

For the present investigation the procedure adopted was similar to that employed by other investigators, *viz.*, burying of weighed samples enclosed in loosely woven

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[1] Annett and Padmanabha Aiyar. *Mem. Dept. Agri. India, Chem. Ser.*, Vol. VIII, No. 10.
[2] Lander and Bhai Balwant Singh. *Jour. Centr. Bur. Anim. Husb.* and *Dairying, India*, I, p. 33.
[3] *Agri. Res. Inst., Pusa, Bull.* No. 182.
[4] *Mem. Dept. Agri. India, Chem. Ser.*, Vol. IX, No. 5. *Jour. Centr. Bur. Anim. Husb. and Dairying, India*, Vol. II, p. 31.

gunny bags in different portions of the silo during its filling, and removing and weighing the bags as they turn up during the utilization of the silage, samples from the bags before and after ensilage being removed and subjected to analysis.

A rectangular pit silo 25 feet long, 15 feet wide and 12 feet deep was selected and the *jowar*, harvested when the grains were hardening, was chaffed to bits about an inch in length and slowly filled in. The filling operation continued from 10th to 27th November, 1927. From 19th November, 1927, watering was resorted to as the crop was rather drier than seemed desirable for ensilage. The harvesting of the crop was always done in the morning and the chaffing and filling was done in the evening between 2-30 and 5-30 P.M. After the filling, the pit was levelled and well trampled down daily. The weather throughout was bright and sunny except on the opening day when there was a slight drizzle. Twelve bags, in four layers of three in each layer, were put in at two, five, eight, and eleven feet, respectively, from the bottom of the pit, filled with a thoroughly mixed sample of the *jowar* ensiled. Along with the filling of the bags, representative samples for analysis were also collected. The positions of the bags are shown in Fig 1., at B_1, B_2 and B_3. T_1 and T_2 are the position of the thermometers put in at 4 feet and 8 feet from the bottom respectively.

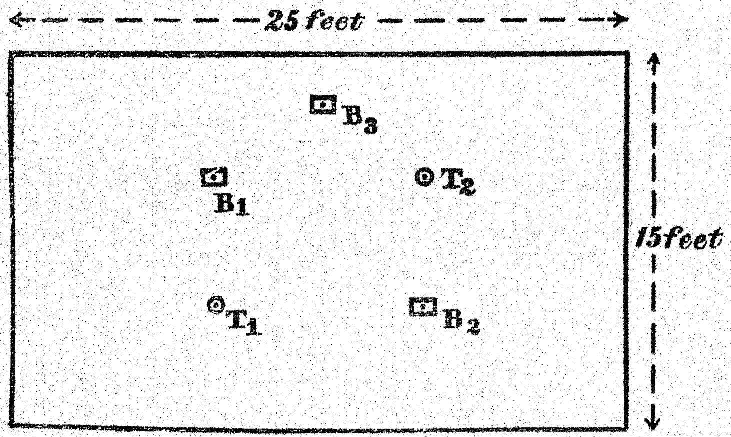


Fig.1.

RECORDING OF TEMPERATURE.

Temperature readings were taken by using the arrangement shown in Fig. 2. It consists of a galvanized iron pipe 1·5 inches in diameter, in which a thermometer, jacketed by a stout walled glass tube, fixed to a wooden cork which just passes easily

through the pipe, was suspended. The thermometer combination was protected against breakage from knocking by having cotton wool padding at the top and

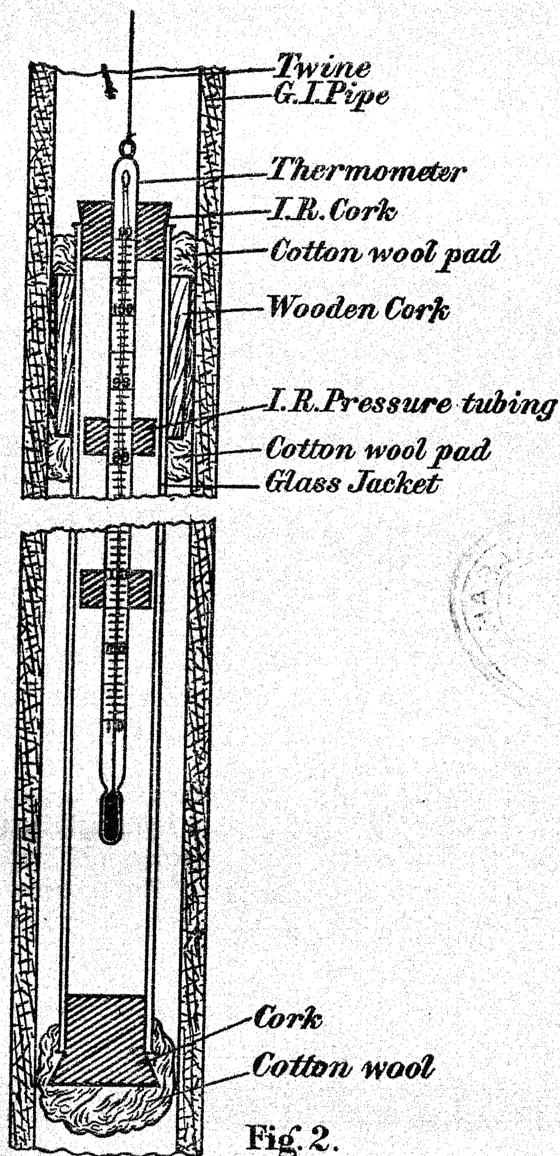
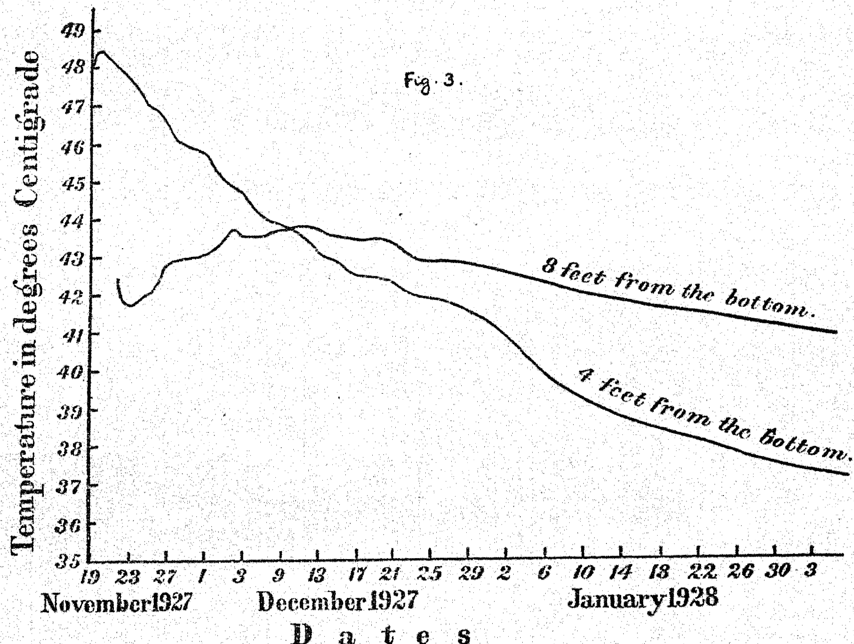


Fig. 2.

bottom. The former also minimised the risk of conduction and convection vitiating the readings at the bottom of the pipe. The thermometer was hauled up quickly

for taking readings after which it was again let down and the pipe closed up. Readings were taken daily. Fig. 3 is a graphical record of the temperature observations.



DISCUSSION OF TEMPERATURE CURVES.

The two curves (Fig. 3) show marked differences; while the one corresponding to the lower level, reaches its maximum temperature of 48·5°C. on the very next day and thereafter registers a steady fall, the other graph, corresponding to the higher level, behaves very differently. It registers 42·5°C. on the first day while there is a fall to 41·8°C. on the next day, and a gradual rise to the maximum of 43·8°C., which is much lower than the temperature attained in the lower level. The time taken for this rise is nearly three weeks. The temperature there continues to remain at or over 43·5°C. for more than two weeks, after which it begins to fall steadily but very slowly. The rate of fall here is considerably less than in the other level.

The higher maximum in the lower level is due to the fact that, owing to the insufficient packing leaving considerable air entangled in the material, heating and fermentation had been going on apace undisturbed for three days. The presence of air enabled the development of a higher temperature, and the delayed putting in of the thermometer caused the recording, practically, of only the maximum attained. Thereafter a gradual cooling off ensued and the graph shows the same.

In the other case, filling was regularly going on and from the date of putting in the thermometer watering was also resorted to. The watering enabled a better

consolidation and consequently a better exclusion of air, resulting in the inhibition of heating up to a large extent. The maximum was also lowered partly by the added water taking up a large quantity of heat to be raised to that temperature. This is further proved by the drop in temperature noted on the next day, which must be due to the draining down of the water added on the previous day which would absorb a large quantity of the heat generated. The amount of water coming down on subsequent days being less, and at a higher temperature, the curve remains steady for the next two days and due to the continuance of fermentation in the whole mass, begins to ascend slowly. Another factor contributing to the rise in temperature is the conduction and radiation from the lower layers, which increases with the settling down of the mass in the pit and the consequent decrease in the distance between the warmer lower layer and the cooler upper layer resulting in a more rapid increase in temperature. This is not seen prominently, because, owing to the stoppage of fermentation, cooling is also going on in the whole mass. A sort of equilibrium is thus established and hence the curve is nearly horizontal—the temperature being steady—for a long period of about two weeks. This also accounts for the very slow cooling taking place thereafter. The same cause—the transmission of a considerable quantity of heat to the upper layers—accounts for the more rapid cooling of the bottom layers.

The character of the silage and the temperature attained agrees quite well with the " sweet dark brown " silage of Amos and Williams [1] who noted a temperature of 45° to 50°C. being developed. Excepting at the top of the tower the temperature obtained at Nagpur[2] was considerably less than that noted in this investigation, only one bag registering a temperature of 44·1°C. Lander and Singh[3] also noted lower maximum temperatures. Much higher temperatures were obtained in the stack by Woodman and Hanley[4]. Woodman and Amos[5] obtained 47·6°C. in the tower when " sweet", but not burnt, silage was produced.

Opening of the silo.

The silo was opened on 21st January, 1929, on one side. Considerable settling had taken place, the level at the top being only 14 feet 3 inches, showing that a further settling of 3 feet 3 inches had taken place after the closing of the pit on 27th November, 1927. A layer of rotten mouldy silage was found at the top which was rejected. Good silage was obtained from 12 feet 9 inches downwards. There was also about 9 to 12 inches thickness of material spoilt all round the sides of the pit. The sinking of the material in the pit is evident from the fact that bags put in at a height of 11 feet from the bottom of the pit were found on removal at a height of 7 feet 6 inches from the bottom, showing a sinking of 3 feet 6 inches. Bags at 2

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[1] Amos and Williams. *Jour. Agri. Sci.*, Vol. XII, p. 323.
[2] Annett and Padmanabha Aiyar, loc. cit.
[3] Lander and Bhai Balwant Singh, loc. cit.
[4] Woodman and Hanley. *Jour. Agri. Sci.*, Vol. XVI, p. 24.
[5] Woodman and Amos. *Jour. Agri. Sci.*, Vol. XVI, p. 539.

feet, 5 feet and 8 feet heights initially, were recovered at heights of 6 inches, 2 feet and 4 feet 6 inches respectively from the bottom, showing a settling of 18 inches to 3 feet 6 inches.

As each bag was turned out, during the utilization of the silage in the pit, it was immediately removed and weighed. The contents was emptied out and the bag reweighed, the amount of silage produced being thus obtained. The silage emptied out was thoroughly mixed and a representative sample removed immediately to the laboratory for analysis.

Quality of silage produced.

The silage produced was of a remarkably uniform character. Excepting the rotten and mouldy silage at the top and sides of the pit, the whole mass had a pleasant sweet aroma. The material looked dark brown in colour. Taking all the characteristics together, the silage obtained in this investigation might be called "sweet dark brown." The bottom layers of the pit had the same sweet smell and dark brown colour, but had in addition a slightly acidic smell. Even for this layer the same nomenclature could well be applied without any appreciable error. That this is the correct nomenclature is proved by the fact that the properties of the silage obtained in this investigation agree well with the method of filling, temperature attained, and even in the layers formed in the pit as set forth in the pamphlet on "Ensilage" issued by the Military Grass Farms Department based on the work of Amos and Woodman[1]. The only difference is that while a layer of sour silage is said to be found at the bottom of the pit, no such layer was noticed, though it must be conceded that the bottom layers were more acidic than the top ones. Amos and Williams[2] say that "sweet dark brown" silage is produced when the temperature attained is between 45°C. and 50°C. In the present instance the maximum attained was 43·8°C. to 48·5°C. Hence we find a close agreement in temperature as well. Thus there is no hesitation in saying that "sweet dark brown" silage was obtained in this experiment.

Method of Analysis.

The dry matter in the green plant before ensilage, as well as in the silage, was obtained by drying down triplicate lots of 300 grm. each, to constant weight in an air oven at 100°C. and finding the average figure. This was corrected for the loss of volatile bases, calculated as crude protein, and volatile organic acids calculated as acetic acid. The dried material was finely ground up in a mill and used for all subsequent analyses. The preparation and analysis of the alcoholic extracts for volatile bases, amino acids, organic acids, etc., was carried out according to the modified method of Woodman[3]. The information gained from the bags is given in the accompanying Tables.

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[1] Amos and Woodman. *Jour. Min. Agri., London*, 1925.
[2] Amos and Williams, loc. cit.
[3] Woodman. *Jour. Agri. Sci.*, Vol. XV, p. 343.

TABLE I.

Changes in the bags during ensilage.

Bag No.	1	2	3	4	5	6	7	8	9	10	11	12
Height of bag from the bottom of the pit when put in.	2′	2′	2′	5′	5′	5′	8′	8′	8′	11′	11′	11′
Height of bag from the bottom of the pit when removed.	0′ 6″	0′ 6″	0′ 6″	2′	2′	2′	4′ 6″	4′ 6″	4′ 6″	7′ 6″	7′ 6″	7′ 6″
Weight of green *Jowar* ensiled in kilos.	16·910	11·280	14·510	14·370	14·300	13·720	14·500	14·130	13.590	14·610	14·920	14·020
Weight of silage produced in kilos.	16·670	11·635	16·400	16·340	13·282	13·172	14·278	14·220	16·605	13·163	15·143	13·900
Per cent. dry matter as ensiled.	29·34	29·77	29·01	30·85	30·30	30·44	29·66	30·78	31·59	28·48	30·42	30·40
Per cent. dry matter in silage.	28·00	27·86	23·94	24·26	30·82	31·15	30·07	28·45	27·11	30·01	28·81	29·18
Total dry matter ensiled in kilos.	4·961	3·358	4·218	4·433	4·333	4·176	4·301	4·349	4·293	4·161	4·539	4·262
Total dry matter in silage in kilos.	4·668	3·241	3·926	3·964	4·093	4·103	4·293	4·046	4·502	3·950	4·363	4·056
Per cent. change in dry matter.	—5·91	—3·48	—6·94	—10·58	—5·54	—1·75	— 0·19	—6·97	+4·87	—5·07	—3·88	—4·83
Date of ensilage	12-11-27	12-11-27	12-11-27	15-11-27	15-11-27	15-11-27	19-11-27	19-11-27	19-11-27	22-11-27	22-11-27	22-11-27
Date of removal	11-3-29	11-3-29	11-3-29	25-2-29	22-2-29	25-2-29	7-2-29	7-2-29	7-2-29	22-1-29	29-1-29	29-1-29

N.B. The dry matter in all cases has been corrected for the loss of volatile bases and volatile organic acids.

TABLE II.

Percentage composition of Jowar before and after ensilage—on dry basis.

Bag Nos.	Crude Protein		Ether Extract		N-Free Extractives		Crude Fibre		Ash		Silica		True Protein		Amides	
	Before ensilage	After ensilage	Before ensilage	After ensilage	Before ensilage	After ensilage	Before ensilage	After ensilage	Before ensilage	After ensilage	Before ensilage	After ensilage	Before ensilage	After ensilage	Before ensilage	After ensilage
1	9·38	9·18	2·02	5·90	49·84	40·44	28·59	34·31	10·17	10·17	4·96	4·66	6·62	4·75	2·76	4·43
2	9·16	9·20	1·98	6·07	50·48	41·32	29·19	33·10	9·19	10·31	4·08	4·60	6·41	5·58	2·75	3·62
3	9·01	9·69	2·01	6·65	47·94	38·62	31·94	34·92	9·10	10·12	3·91	4·32	6·34	5·30	2·67	4·39
4	9·51	9·93	2·14	6·16	46·36	38·09	31·37	34·03	10·62	11·79	4·36	5·03	6·31	5·60	3·20	4·33
5	9·60	9·26	2·04	4·96	50·29	41·25	27·23	34·55	10·84	9·98	4·93	4·02	6·45	4·84	3·15	4·42
6	10·05	9·79	2·16	4·64	45·09	39·09	30·62	34·97	12·08	11·51	5·85	5·58	7·35	5·78	2·70	4·01
7	8·83	10·07	1·57	4·96	48·86	45·63	31·87	29·36	8·87	9·98	3·11	4·70	6·25	6·05	2·58	4·02
8	8·35	9·36	1·57	5·02	50·77	43·89	30·69	32·14	8·62	9·59	3·02	4·08	5·98	5·39	2·37	3·97
9	9·41	10·23	1·70	5·20	49·65	43·35	30·31	31·60	8·93	9·62	3·47	3·86	6·37	5·16	3·04	5·07
10	8·85	7·85	2·10	3·85	51·21	51·70	28·69	28·17	9·15	8·43	3·15	3·30	6·31	4·28	2·54	3·57
11	9·93	9·00	2·38	4·21	50·87	47·58	27·76	29·92	9·06	9·29	3·39	3·63	6·92	4·86	3·01	4·14
12	9·63	9·11	2·31	4·26	50·90	48·06	28·10	29·13	9·06	9·44	3·62	3·68	6·81	5·77	2·82	3·34

N.B. Crude protein and ether extract have been corrected for volatile bases and volatile organic acids respectively.

TABLE III.

Changes in the various constituents of the bags during ensilage (in grammes on dry basis).

Bag No.	TOTAL DRY MATTER			ORGANIC MATTER			TOTAL CARBOHYDRATES			N-FREE EXTRACTIVES		
	Green *Jowar*	Silage	Gain or Loss %	Green *Jowar*	Silage	Gain or Loss %	Green *Jowar*	Silage	Gain or Loss %	Green *Jowar*	Silage	Gain or Loss %
1 .	4,961·0	4,668·0	—5·9	4,456·7	4,228·8	—5·1	3,891·5	3,577·2	—8·1	2,474·6	2,094·8	—15·4
2 .	3,358·0	3,241·0	—3·5	3,049·6	2,931·6	—3·9	2,675·7	2,473·0	—7·6	1,696·4	1,479·0	—12·8
3 .	4,218·0	3,926·0	—6·9	3,835·4	3,560·3	—7·2	3,372·0	2,969·9	—11·9	2,029·0	1,708·3	—15·8
4 .	4,433·0	3,964·0	—10·6	3,964·6	3,533·8	—10·9	3,451·0	2,946·3	—14·6	2,068·0	1,704·0	—17·6
5	4,333·0	4,093·0	—5·5	3,865·7	3,712·3	—4·0	3,364·0	3,169·8	—5·8	2,190·3	1,851·4	—15·5
6 .	4,176·0	4,103·0	—1·8	3,673·3	3,660·4	—0·4	3,165·1	3,105·6	—1·9	1,891·0	1,761·5	—6·9
7 .	4,301·0	4,293·0	—0·2	3,919·9	3,883·3	—0·9	3,473·4	3,266·1	—6·0	2,104·5	2,060·6	—2·1
8 .	4,349·0	4,046·0	—7·0	3,974·9	3,681·8	—7·4	3,544·2	3,135·6	—11·5	2,211·7	1,915·1	—13·4
9 .	4,293·0	4,502·0	+4·9	3,910·1	4,089·6	+4·6	3,433·8	3,427·7	—0·2	2,133·6	2,072·4	—2·9
10 .	4,161·0	3,950·0	—5·1	3,782·0	3,625·2	—4·1	3,327·8	3,176·0	—4·6	2,138·8	2,094·7	—2·1
11 .	4,539·0	4,363·0	—3·9	4,129·9	3,970·4	—3·9	3,574·0	3,411·9	—4·5	2,320·5	2,146·9	—7·5
12	4,262·0	4,056·0	—4·8	3,877·8	3,686·2	—4·9	3,371·4	3,162·4	—6·2	2,179·0	2,021·4	—7·2
Average .	..	..	—4·2	..	..	—4·0	..	..	—6·9	..	..	—9·9

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TABLE III—*contd.*

Changes in the various constituents of the bags during ensilage (in grammes on dry basis)—contd.

Bag No.	Crude Fibre			Ether Extract *			Crude Protein †			True Protein		
	Green *Jowar*	Silage	Gain or Loss %	Green *Jowar*	Silage	Gain or Loss %	Green *Jowar*	Silage	Gain or Loss %	Green *Jowar*	Silage	Gain or Loss %
1	1,416·9	1,482·4	+4·6	100·1	254·9	+154·7	465·1	396·7	—14·7	328·1	205·2	—37·5
2	979·3	994·0	+1·5	66·5	182·3	+174·1	307·4	276·3	—10·1	214·9	167·5	—22·1
3	1,343·0	1,261·6	—6·1	84·5	240·3	+184·4	378·9	350·1	—7·6	266·6	191·6	—28·1
4	1,383·0	1,242·3	—10·2	94·5	224·9	+138·0	419·1	362·6	—13·5	278·1	204·3	—26·5
5	1,173·7	1,318·4	+12·3	87·9	189·1	+115·1	413·8	353·4	—14·6	278·0	184·9	—33·5
6	1 274·1	1,344·1	+5·5	89·9	178·5	+98·6	418·3	376·3	—10·0	305·8	222·1	—27·4
7	1,368·9	1,205·5	—11·9	67·8	203·8	+202·8	379·2	413·4	+9·0	268·5	248·5	—7·5
8	1,332·5	1,220·5	—8·4	68·3	190·5	+178·9	362·4	355·7	—1·8	259·7	204·6	—21·2
9	1,300·2	1,355·3	+4·2	72·7	223·0	+207·2	403·6	438·9	+8·7	273·2	221·3	—19·0
10	1,189·0	1,081·3	—9·1	87·2	147·7	+69·4	367·0	301·5	—17·8	261·6	163·2	—37·6
11	1,253·5	1,265·0	+0·9	107·3	177·9	+65·8	448·6	380·6	—15·2	312·4	205·5	—34·2
12	1,192·4	1,141·0	—4·3	97·8	167·0	+70·8	408·6	356·8	—12·7	289·1	226·0	—21·8
Average	..	..	—1·8	..	..	+138·3	..	..	—8·4	..	..	—26·4

* Corrected for loss of volatile organic acids.

† Corrected for loss of volatile bases.

TABLE III—*concld.*

Changes in the various constituents of the bags during ensilage (in grammes on dry basis)—concld.

Bag No.	AMIDES			TOTAL ASH			SOLUBLE ASH			INSOLUBLE ASH		
	Green *Jowar*	Silage	Gain or Loss %	Green *Jowar*	Silage	Gain or Loss %	Green *Jowar*	Silage	Gain or Loss %	Green *Jowar*	Silage	Gain or Loss %
1	137·0	191·5	+39·8	504·3	439·2	—12·9	258·6	237·9	—8·0	245·7	201·3	—18·1
2	92·5	108·8	+17·6	308·4	309·4	+0·3	171·4	171·0	0·0	137·0	138·1	+0·8
3	112·3	158·5	+41·1	382·6	365·7	—4·4	218·1	290·5	—3·9	164·5	156·2	—5·0
4	141·0	158·3	+12·3	468·4	430·2	—8·2	276·4	246·5	—10·8	192·0	183·7	—4·3
5	135·8	168·5	+24·1	467·3	380·7	—18·5	255·0	227·2	—10·9	212·3	153·5	—27·7
6	112·5	154·2	+37·1	502·7	442·6	—12·0	259·3	228·1	—12·0	243·4	214·5	—11·9
7	110·7	164·9	+49·0	381·1	409·7	+7·5	247·7	216·7	—12·5	133·4	193·0	+44·7
8	102·7	151·1	+47·1	374·1	364·2	—2·6	242·9	209·2	—13·9	131·2	155·0	+18·1
9	130·4	17·6	+66·9	382·9	412·4	+7·7	234·1	246·8	+5·4	148·8	165·6	+12·7
10	105·4	153·3	+31·4	379·0	324·8	—14·3	248·6	198·0	—20·4	130·4	126·8	—2·8
11	136·2	175·1	+28·6	409·1	392·6	—4·0	256·1	239·2	—6·6	153·0	153·4	+0·2
12	119·5	130·8	+9·5	384·2	369·8	—3·7	230·8	225·8	—2·2	153·4	144·0	—6·1
Average	..	..	+33·7	..	..	—5·3	..	..	—8·0	..	..	0·0

Discussion of results.

(*a*) *Changes in the moisture, dry matter and organic matter.* Table I contains some of the information gained from the bags. It will be seen that the green weight of the material ensiled is nearly equal to the amount of wet silage produced except in bags 3, 4 and 9. This is in spite of the fact that large amounts of water have been added during ensilage. It is evident, therefore, that the sides and bottom of the pit have absorbed considerable quantities of the liquid drained down by pressure. The silage produced is generally wetter than the ensiled material, only bags 4, 5 and 6 being exceptions, the maximum increase in bag 5 being 0·7 per cent. above the dry matter percentage of the green crop. The maximum decrease in the percentage dry matter of the silage is 6·6 per cent. in bag 4. The silage bags which have grown heavier, naturally show a greater loss in the percentage dry matter.

The loss in the total dry matter on ensilage due to fermentation works out, on an average, to only 4·2 per cent. (Table III), when allowances have been made for the loss of volatile bases and volatile organic acids on drying. The magnitude of the change introduced by the correction could easily be gauged by comparing the loss of total dry matter estimated by neglecting the corrections which is 9·3 per cent., with the above figure obtained when the necessary corrections are made. Throughout this communication only the corrected values have been used. There are wide fluctuations in the dry matter change, from a gain of 4·87 per cent. in bag 9 to a loss of 10·58 per cent. in bag 4. Bag 9, however, is seen to behave rather peculiarly in all respects and this peculiarity is also shared by bag 7. A satisfactory explanation, however, cannot be given for these peculiarities.

The loss noticed here is much less than that obtained at Nagpur[1] which is 7·5 per cent. if all silos are considered and 10·7 per cent. if only pit silos are included. The crop ensiled at Nagpur was also *Jowar*. Lander and Singh[2] in the Punjab obtained a loss of 15·7 per cent. which is also considerably higher than that noticed at Bangalore. The losses obtained at Cambridge[3] are also higher, their minimum loss being 7·7 per cent. in the case of "acid brown" silage, the other types giving higher losses. But it must be admitted that the ensiled material was absolutely different in the experiments at Lyallpur and Cambridge and even the climatic conditions were entirely different at the latter place. Perhaps these reasons might account for the lack of agreement in the figures. The only figure that is near enough to the loss obtained here, is that recorded by Ragsdale and Turner of Missouri Agricultural Experiment Station, for the loss of dry matter by fermentation during ensilage of corn, *viz.*, 4·01 per cent.[4] The loss of organic matter follows closely the loss of dry matter. The loss noted here is 4·0 per cent. which is slightly less than the loss of 4·2 per cent. noted above for the total dry matter.

[1] Annett and Padmanabha Aiyer, loc. cit.
[2] Lander and Bhai Balwant Singh, loc. cit.
[3] Amos and Woodman. *Jour. Agri. Sci.*, XV, p. 344.
[4] Quoted in *U. S. Dept. Agri. Farmer's Bulletin*, 578.

(*b*) *Changes in the nitrogenous constituents.* Considerable changes take place in the proteins of the plant during ensilage. A very important observation is the actual loss of crude protein to the extent of 8·4 per cent. (Table III). Annett and Aiyer[1] obtain an average loss of 8·9 per cent. Amos and Woodman[2] notice a loss of 0·6 per cent. to 21 per cent. in the same constituent. The same authors[3] in a study of clamp silage obtain a loss of 9·6 per cent. Woodman and Amos[4] obtain an average loss of 8·2 per cent. in the case of " green fruity " silage and no change in " acid brown " silage for crude protein. Woodman and Hanley[5] in their study of stack silage noted an average loss of 11·3 per cent. When sugar beet tops were ensiled, a loss of 7·8 per cent. was recorded by Woodman and Amos[6]. The nearness of all these figures, obtained in different places, with different crops, and ensiled under different conditions, shows that the loss noted in the present investigation is about the loss experienced always on ensilage.

Considerable breaking down of the true protein to the lower degradation products as volatile bases, amino acids, etc., takes place, ranging from 7·5 per cent. to 37·6 per cent. giving an average loss of true protein to the extent of 26·4 per cent. of the total original content. (Table III.) This loss is partly shown as an increase of 33·7 per cent. of amides. These results go to confirm the observation of Amos and Woodman[7] that the loss of true protein and the production of amides is a sign of good silage. Lander and Singh[8] have also been able to subscribe to the above remark. Annett and Aiyer[9], however, could not agree, as they obtained good silage without the large loss of true protein and the corresponding increase of amides.

TABLE IV.

Amount of true protein expressed as percentage of crude protein.

Bag No.	1	2	3	4	5	6	7	8	9	10	11	12	Average
Green *Jowar* .	70·54	69·91	70·36	66·36	67·18	73·11	70·81	71·66	67·69	71·28	69·64	70·75	69·94
Silage . . .	51·73	60·62	54·73	56·34	52·32	59·02	60·11	57·52	50·42	54·13	53·99	63·34	56·19

Table IV shows the extent of the degradation of true protein. The average proportion of true to crude protein in the green plant is seen to be 69·94 per cent. which is reduced to 56·19 per cent. as the result of ensilage.

[1] Annett and Padmanabha Aiyer, loc. cit.
[2] Amos and Woodman. *Jour. Agri. Sci.*, XII, p. 342.
[3] Amos and Woodman, loc. cit.
[4] Woodman and Amos. *Jour. Agri. Sci.*, XIV, p. 99.
[5] Woodman and Hanley. loc. cit.
[6] Woodman and Amos. *Jour. Agri. Sci.* XVI, 400.
[7] Amos and Woodman, loc. cit.
[8] Lander and Bhai Balwant Singh, loc. cit.
[9] Annett and Padmanabha Aiyer, loc. cit.

TABLE V.

Changes in volatile bases and amino acids.

Bag No.	Volatile Bases*		Amino acids*		Asparagin	
	Before ensilage	After ensilage	Before ensilage	After ensilage	Before ensilage	After ensilage
1 .	4·5	150·8	29·3	47·3	27·3	6·8
2 .	3·0	100·6	19·6	33·0	18·2	2·4
3 .	3·9	123·3	21·3	42·6	23·4	3·4
4 .	9·5	129·4	21·0	31·2	31·7	6·7
5 .	11·4	128·0	26·6	32·0	43·1	5·4
6 .	7·3	125·0	29·2	24·7	38·6	2·7
7 .	5·8	65·0	25·1	57·3	35·0	2·9
8 .	5·6	107·3	18·8	36·4	31·2	8·7
9 .	3·6	62·8	18·0	83·0	27·2	10·1
10 .	3·9	26·4	41·1	79·2	23·6	..
11 .	4·0	40·6	7·9	69·1	21·0	6·1
12 .	3·7	44·7	20·5	82·0	22·5	11·3

There is marked increase of volatile bases after ensilage. The amino acids have also increased but to a much smaller extent. Another important fact is that while the volatile bases show a greater increase as we go down the pit, the amino acids show an exact reverse of this phenomenon. These observations are in confirmation of the results obtained by Lander and Singh.[1] They observed a stoppage of the production of amino acids from protein decomposition after two or three months, while the volatile bases continued to increase. The possibility of volatile bases being formed by the decomposition of amides could not be ruled out either, as the upper bags in which the amino acids are high contain less volatile bases while the lower ones show a much larger production of the same and considerably less augmentation of amino acids. There is also the probability of the volatile bases being washed down by the draining juice thus depleting the upper layers and enriching the lower ones proportionately. The amino acids show no such leaching losses.

* Calculated as crude protein.

[1] Lander and Bhai Balwant Singh, loc. cit.

From Table V another very interesting fact will be noted, *viz.*, the practically total disappearance of asparagin. Asparagin was estimated,[1] by boiling the residual liquid after the estimation of volatile organic acids, with 10 per cent. of its volume of concentrate hydrochloric acid for one hour under reflux and then estimating the ammonia liberated. The fact of the disappearance of asparagin also lends weight to the conclusion, that, amides and amino acids, which might at first be formed by the decomposition of true protein, are gradually converted to volatile bases.

TABLE VI.

Ratio of volatile bases to amino acids before and after ensilage.

Bag No.	1	2	3	4	5	6	7	8	9	10	11	12
Green *Jowar*	0·15	0·15	0·18	0·45	0·43	0·25	0·23	0·30	0·20	0·09	0·51	0·18
Silage	3·19	3·05	2·89	4·15	4·00	5·06	1·13	2·95	0·76	0·33	0·59	0·55

The ratio of volatile bases to amino acids is indeed high in bags 1 to 8 as has been observed by all Indian workers[2 & 3] without in the least affecting the quality of the silage. The present work also goes to confirm the above observations. Though as shown in the above table the ratio of volatile bases to amino acids is high in bags 1 to 8, numbers 9 to 12 have a lower value and may be said to correspond to the dictum of Amos and Woodman[4] to a small extent. But these latter bags can under no circumstances be called spoilt silage and hence the nett conclusion is that the English observations do not hold good here. The only noticeable difference was that while bags 7 to 12 had a sweet smell, numbers 1 to 6 had a slightly acidic smell which was most perceptible in bags 1 to 3. So the statement of the Cambridge workers[6] that "a high ratio of volatile bases to amino acids is a sign of spoiling" lacks confirmation.

As a result of several experiments conducted by the Nutrition Section with silage, it has been noticed that the protein digestibility is low. This entirely corroborates previous work by others. It has also been noticed that a depression of the protein digestibility of the plant results by ensilage. A variety of reasons have been attributed to the low digestibility of the silage protein, but no account seems to have been taken of the loss sustained in the true as well as the crude protein during the ensilage. The loss noted above must naturally be the most valuable protein since it would be the most easily digestible. The loss of the most easily digestible protein leaves only the poorer and less digestible portion in the silage. The extensive

[1] Allen. *Commercial Organic Analysis*, Vol. VII, p. 237 (revised by Davis).
[2] Annett and Padmanabha Aiyar, loc. cit.
[3] Lander and Bhai Balwant Singh, loc. cit.
[4] Amos and Woodman, loc. cit.
[5] Amos and Woodman. loc. cit.

decomposition noticed in the true protein is also a very important factor in lowering the value and digestibility of the residual proteins. Hence the combined effect of the above causes might, more than anything else, account for the low digestibility of the silage protein.

(c) *Changes in the ether extract.* During ensilage large quantities of organic acids are produced as the result of bacterial activity on the carbohydrates of the plant. All these acids, being soluble in ether, are included in the ether extract. Hence the increase in the ether extract measures the extent of bacterial activity. From Tables II and III, it will be noticed that the ether extract has increased enormously, an average increase of 138·3 per cent. being noticed.

TABLE VII.

Changes in ether extract and organic acids during ensilage.

Bag No.	Total ether extract		Volatile organic acids*		Non-volatile organic acids†	
	Green *Jowar*	Silage	Green *Jowar*	Silage	Green *Jowar*	Silage
1	100·1	254·9	..	196·1	62·8	4·6
2	66·5	182·3	..	138·0	41·8	6·5
3	84·5	240·3	..	190·6	57·9	11·5
4	94·5	224·9	13·1	183·7	81·8	9·2
5	87·9	189·1	9·1	150·0	76·5	3·7
6	89·9	178·5	6·2	134·1	78·2	5·4
7	67·3	203·8	..	121·4	53·8	87·4
8	68·3	190·5	1·2	140·6	56·1	7·9
9	72·7	223·0	..	149·3	41·9	135·3
10	87·2	147·7	10·7	85·7	72·5	148·5
11	107·3	177·9	16·3	94·8	110·5	142·2
12	97·8	167·0	14·1	94·6	92·3	162·3

* Calculated as acetic acid.
† Calculated as lactic acid.

The data presented in the above Table are rather peculiar. That the volatile acids would increase to a considerable extent was only expected, but the phenomenon

of the practically complete destruction of non-volatile acids in bags 1 to 6 and 8 comes rather as a surprise. This destruction lends support to the suggestion that long continued preservation enables the development of volatile organic acids even at the expense of the non-volatile acids. But the period separating the unearthing of the different layers is not enough to lend strong support to this view. Anyhow this peculiarity is similar to the observation of Lander and Singh[1].

TABLE VIII.

Ratio of volatile to non-volatile organic acids after ensilage.

Bag No.	1	2	3	4	5	6	7	8	9	10	11	12
Ratio	42·6	21·2	16·6	20·0	40·5	24·8	1·4	17·8	1·1	0·6	0·7	0·6

The ratio of volatile to non-volatile organic acids given in Table VIII shows that in bags 1 to 6 and 8 the ratio is very high, whereas in bags 7 and 9 to 12 the ratio is low. According to the observation of Amos and Woodman[2], such high ratios indicate spoiling. No sort of spoiling was, however, noticed in this silage, excepting a very slight acidic smell in bags 1 to 6. Butyric acid was entirely absent and the silage, as has already been stated, was of excellent quality. But Woodman and Amos[3] have taken care to point out that, though a high ratio of volatile to non-volatile organic acids is a sign of spoiling, it is safer to rely on (1) the ratio of volatile to non-volatile organic acids, (2) the amount of organic acids and (3) the type of volatile organic acids. Now, taking all these into consideration, the present observations cannot be held to contradict the observations at Cambridge. Similar results to those recorded here were, however, obtained by Annett and Aiyer[4] as well as by Lander and Singh[5].

(*d*) *Changes in the carbohydrates.* The changes undergone by the carbohydrates might conveniently be considered under the following heads:—

(*i*) *Changes in the N free extractives.* These should naturally be the heaviest losers since the oxidative changes and bacterial activity are dependent on the soluble carbohydrates for their progress. The carbohydrates are oxidised to organic acids to a considerable extent and partly also to carbon dioxide and water. The organic acids may be volatile, as acetic acid, or non-volatile as lactic acid. When sweet or acid silages are produced, these acids are present in varying amounts, but the presence or otherwise of butyric acid is the main criterion which determines whether a silage is sour or not. All these acids are estimated as ether extract, as has already

[1] Lander and Bhai Balwant Singh, loc. cit.
[2] Amos and Woodman, loc. cit.
[3] Woodman and Amos, loc. cit.
[4] Annett and Padmanabha Aiyar, loc. cit.
[5] Lander and Bhai Balwant Singh, loc. cit.

been noted. The loss of nitrogen-free extractives varies from 2·1 to 17·6 per cent. with an average loss of 9·9 per cent. Annett and Aiyer[1] obtained a loss of 13 per cent., while Lander and Singh[2] noted a much higher loss of 27 to 30 per cent. Amos and Woodman[3] have also obtained losses of 15 to 20 per cent. according as the silage was " acid brown " or " sweet." They have obtained very high losses of about 49·7 per cent. when sour silage was produced in the clamp[3]. In a study of stack silage, Woodman and Hanley[4] obtained a loss of about 17 per cent.

(*ii*) *Changes in the crude fibre.* Crude fibre has always been found to be attacked by bacteria and broken down to varying extents. Losses in the region of 5 per cent. have been obtained by the workers in Cambridge, while higher losses of about 11 to 15 per cent. in the Punjab[5] and 2C per cent. in Nagpur[6], have been noted. In the present case Table III shows an average loss of 1·8 per cent. only, while individual variations are considerable. Some bags have even shown an actual increase, probably because of the unsatisfactory nature of the crude fibre determination. Such increases have also been obtained by Woodman and Hanley[7].

(*iii*) *Changes in the total carbohydrates.* The figures for the losses in total carbohydrates are far more valuable. They represent the combined losses of fibre and nitrogen-free extractives. We have no criterion by which we could say that the oxidative or bacterial activity went on at the expense of the nitrogen-free extractives, or crude fibre, or to what extent in either case. Hence the combined results have better value. The total carbohydrates show a loss of 6·9 per cent. which is considerably less than the loss obtained by other workers. As has already been noted, Amos and Woodman found a loss of 14·7 per cent. when " acid brown " silage was produced which rose to about 46 per cent. when " sour " silage was produced in the clamp. Considering these, the losses obtained here are very small. The losses are only partly accounted for by the organic acids estimated as ether extract. Hence there is an actual loss and this is also what others have concluded.

(*e*) *Changes in the inorganic constituents.* A critical and exhaustive study of the changes affecting the various constituents was undertaken since much attention does not seem to have been paid to this aspect by others. There is a loss of 5·3 per cent. on the average, of the total ash (Table III) most probably by the carrying away of the soluble components by the drainage juices. This is evidenced by the fact that the average loss of silica is *nil*, whilst the soluble ash has disappeared to the extent of 8 per cent. Other workers too have noticed slight changes in the ash percentages and have ascribed them to the leaching action of the drainage juice. The changes have not called forth any detailed remark from them.

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[1] Annett and Padmanabha Aiyar, loc. cit.
[2] Lander and Bhai Balwant Singh, loc. cit.
[3] Amos and Woodman, loc. cit.
[4] Woodman and Hanley, loc. cit.
[5] Lander and Bhai Balwant Singh, loc. cit.
[6] Annett and Padmanabha Aiyar, loc. cit.
[7] Woodman and Hanley, loc. cit.

TABLE IX.

Changes in the total mineral content of bags during ensilage.

Bag No.	P_2O_5		CaO		MgO		SO_3		Na_2O		K_2O	
	Green *Jowar*	Silage	Green *Jowar*	Silage	Green *Jowar*	Silage	Green *Jowar*	Silage	Green *Jowar*	Silage	Green *Jowar*	Silage
1	24·8	22·1	21·0	18·5	30·2	20·1	4·7	7·3	2·1	4·5	100·6	114·5
2	16·8	15·6	14·4	13·3	19·9	14·5	2·9	5·6	3·7	3·5	77·1	80·3
3	20·8	18·0	17·7	14·5	24·3	17·2	5·2	6·5	3·5	3·2	76·6	92·2
4	21·2	20·2	19·7	18·6	28·9	19·2	5·4	7·9	1·6	7·0	112·7	118·7
5	20·5	16·8	19·6	16·8	26·5	17·4	5·2	8·2	4·0	5·9	81·9	106·0
6	20·6	18·4	21·9	18·3	28·9	18·0	6·6	9·0	6·0	3·6	110·4	106·9
7	19·8	19·7	16·4	20·2	19·1	22·4	..	9·1	11·8	13·7	96·5	110·0
8	20·0	18·1	15·3	16·9	18·3	19·7	..	7·3	14·6	24·8	114·3	104·7
9	19·8	22·5	17·6	21·6	19·8	24·3	..	7·8	14·9	12·2	103·4	113·6
10	22·0	17·5	18·3	16·8	20·7	19·6	..	6·3	17·5	5·9	95·0	89·8
11	24·5	21·8	22·3	21·1	25·1	25·0	..	5·8	38·3	10·8	111·8	95·9
12	22·9	20·9	20·5	20·9	23·3	25·1	..	6·3	2·3	8	102·6	100·6

An examination of Table IX reveals the fact that P_2O_5 has been lost to the extent of about 9 per cent. and the loss has been fairly uniform in all bags. A loss of 3 to 4 per cent. of CaO has also taken place. These two constituents are not affected by leaching to different extents, as the different layers do not show variations in loss. MgO behaves somewhat differently since the top bags show no change, while the bottom ones show considerable losses which in some cases amount to over a third of the total original content. SO_3 alone is peculiar since all bags show a decided increase. This shows that some neutral sulphur has been oxidised to sulphate during ensilage. The neutral sulphur probably has been produced by the decomposition of proteins which always takes place during ensilage. In these determination only the oxidised sulphur was estimated and hence this peculiarity. Potash being soluble, one would expect it to be washed down by the draining liquid and that is what is actually noticed. The top bags show a loss while the bottom ones show an increase. This is a typical instance of the changes brought about by leaching. Soda also behaves similarly to potash.

Table X.

Content of water soluble minerals per 100 grammes dry matter expressed as N. acid or base in C. C.

Bag No.	Cl_2		P_2O_5		SO_3		CaO		MgO		K_2O	
	Green *Jowar*	Silage	Green *Jowar*	Silage	Green *Jowar*	Silage	Green *Jowar*	Silage	Green *Jowar*	Silage	Green *Jowar*	Silage
1	17·51	25·01	28·66	2·98	2·50	7·14	..	1·25	13·76	17·96	53·81	64·60
2	17·59	19·26	30·77	7·48	3·07	5·38	..	1·26	14·83	19·55	42·37	70·13
3	13·48	21·84	29·67	8·86	1·90	8·50	..	1·99	15·25	17·82	48·53	66·99
4	18·04	26·40	19·83	5·24	2·97	4·19	..	1·47	14·95	17·56	52·12	63·56
5	18·40	25·35	22·11	3·99	2·42	3·19	..	2·24	13·98	17·40	55·04	71·75
6	17·92	23·46	25·10	5·24	3·01	3·14	..	2·20	14·51	15·80	52·77	68·72
7	20·91	23·83	28·83	18·03	0·93	3·86	..	2·88	14·25	15·54	55·12	48·67
8	21·18	24·21	28·45	5·76	0·89	6·91	..	1·21	13·68	13·04	47·38	38·33
9	18·83	23·43	31·90	32·87	1·16	5·38	..	4·18	13·32	18·03	52·44	28·24
10	16·63	24·94	36·44	55·02	0·60	3·14	..	5·14	20·36	18·45	46·39	55·02
11	18·31	23·84	47·78	9·61	0·30	3·30	..	8·84	24·03	23·48	38·72	44·22
12	18·84	22·84	42·77	43·51	0·60	3·26	..	7·61	21·51	24·61	38·74	57·10

To get a better idea of what happens to the water soluble minerals, a study of the mineral content of the aqueous extract of green *jowar* as well as of silage was made. The actual extract used was the alcoholic extract, prepared as described above, employed for the estimation of volatile bases, amino acids, etc. The chlorides were estimated, in the residue obtained by evaporating off the alcohol from the above solution, by the Volhard-Arnold method. In the estimation of the other minerals 200 c.c. of the alcoholic extract was evaporated to dryness and the residue carefully ashed. The ash was taken up in dilute HCl and this solution was employed. The usual methods were employed for the various constituents. The analysis is given in Table X.

The above Table contains some very interesting results. It shows that chlorides have increased as a result of ensilage, and further the increase is seen to be greater in the lower bags than in the upper ones. The last observation falls into line with the expectations of leaching already noticed. The behaviour of K_2O and MgO further confirm the washing down hypothesis of the soluble chlorides. They all show a considerable increase in the lower bags, while the upper ones show no increase or only slight increases.

The behaviour of the soluble P_2O_5 is rather peculiar. The uppermost bags are not much affected, while the lower ones show a practically complete loss of the same. The loss of such highly soluble P_2O_5 might possibly diminish the value of ensilage.

The oxidation of neutral sulphur already noticed is repeated here in the same manner. Here too the increase is more in the upper layers and less in the lower ones, as has already been noticed in Table IX.

Besides these, a very important feature is the development of water soluble CaO. While before ensilage this constituent was entirely absent (Table X), after ensilage there has been produced lime in this very easily assimilable form. The amount thus rendered soluble is in no way inconsiderable. On the average, more than a fifth of the total lime content of the resultant silage is in this soluble form. Perhaps the rest of the lime of the plant, or a major portion thereof, has been rendered more easily available as the result of ensilage. Any such effect must have a very high value in the utilization of the silage by the animal. It might be mentioned here that, whenever silage has been employed by the Nutrition Section, it has invariably beaten all the other fodders in the matter of growth production in young calves. Another point is also the fact that greater water soluble lime has been produced in the bags where larger amounts of non-volatile acids have been produced. Whether there is any connection and if so, what it is, cannot at present be stated. More work is necessary and is in progress here.

SUMMARY.

Experiments have been carried out in Bangalore to study the nature and extent of the changes taking place during the ensilage of *jowar* (*Sorghum vulgare*).

The filling of the pit silo employed, and the method of experiment are described.

Temperature changes were recorded by a special arrangement and a graphical record is given and discussed.

Sweet dark brown silage of excellent quality was produced.

The weight of moist silage produced is slightly more than the green matter put in because of the large amount of water added.

The losses in the dry matter and organic matter were considerably less than that obtained by other workers in India or England but was in agreement with American results.

A loss of crude protein of about the same order as observed by others was noticed.

A high ratio of volatile bases to amino acids was noticed in several bags without the silage being in the least spoilt. This agrees with Indian results but differs from English observations.

A considerable breaking down of true protein takes place during ensilage. This agrees with the conclusions of all workers but those of Annett and Aiyar.

A practically complete destruction of asparagin takes place on ensilage, suggesting the breaking down of amides in the process.

A high content of volatile acids and a low content of non-volatile acids has been noted in the majority of bags. This agrees with Indian observations. The higher proportion of volatile acids did not indicate a spoilt silage as has been suggested by English workers. Butyric acid was entirely absent.

Carbohydrates are broken up and oxidised to organic acids but the loss of carbohydrates is less than has been estimated by others.

There has been a loss in the total and soluble ash and no change in silica.

P_2O_5 is lost to a considerable extent as the result of ensilage, the water soluble portion being practically all lost.

Though there has been a slight loss in the total lime content, a portion has been rendered water soluble.

The chlorides and alkalis as well as MgO show the effect of the leaching action of the drainage liquid.

There has been an oxidation of neutral sulphur as the result of ensilage.

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